International Journal of Latest Trends in Engineering and Technology
Vol.(17)Issue(3), pp.027-035
DOI: http://dx.doi.org/10.21172/1.173.04
e-ISSN:2278-621X

NECESSITY OF CLASSIFICATION OF SOIL FOR EVALUATING BEARING CAPACITY OF SHALLOW FOUNDATIONS

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Abstract- To determine the bearing capacity and settlement from theoretical methods suggested by several scientists, laboratory test results conducted on undisturbed soil samples are required. But it is extremely difficult to collect undisturbed soil samples of cohesionless soils.In this situations, soil parameters are determined from field tests only. SPT is one of the most economical, simple and reliable field test which is generally used in cohesionless soils. Number of empirical relationships are available between corrected N- values and relative are density, unit weight, angle of internal frication etc for cohesionless soils. Bearing capacities and settlement of shallow foundations founded on cohesionless soils are determined based on corrections suggested by different scientists.

I. INTRODUCTION

Ultimate or safe or allowable bearing capacity and settlement of shallow foundations can be estimated from known theoretical methods suggested by Terzaghi, Meyerhof, Skempton and other researchers, based on soil properties of site soil. To determine the bearing capacity and settlement from theoretical methods, it is necessary to collect undisturbed soil samples from field for determining field unit weight, field moisture content, shear strength parameters, consolidation characteristics etc from laboratory test results.

But it is extremely difficult to collect undisturbed soil samples of granular soils for triaxial tests, field unit weight of soil etc. Hence only field tests (in-Situ tests) are required to determine soil properties to evaluate bearing capacity and settlement of foundations.

Standard penetration test is one of the most economical, sissmple and reliable field tests (in-Situ tests) which is commonly used for cohesionless soils. There is a number of empirical relationships available between N-values and relative density, unit weight of soil, angle of internal friction etc of cohesionless soils. Classification of coarse-grained soils (Compactness of granular soils) can also be calculated from corrected N-values. Classification of soil can also correlated with engineering properties of granular soils. In this paper, we shall discuss how N-Values are used to classify granular soils, its bearing capacities and settlement of shallow foundations founded on cohesionless soils.

II. CLASSIFICATION OF SOILS

The purpose of soil classification is to arrange various types of soil into groups based on their index properties. Soils possessing similar characteristics can be placed in the same group. It is more convenient to study the behaviour of groups than that of individual soils. It is meant essentially to provide a language of communication between engineers.

Soil classification system should be satisfy the following basic requirements:

- It should have a limited number of groups.
- It should be based on the index properties.
- It should be simple and should use the terms which are easily understood.

A geotechnical engineer is interested to know the suitability of a soil as a foundation or a construction materials. Mostly soil classification methods are used simple index properties for placing a soil in a certain group. The most commonly used properties are the grain size distribution and plasticity. It gives idea about its engineering behaviour. The soil classification is not suitable for design of structures. For design of large

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structures, the engineering properties should be determined by conducting elaborate tests on undistributed soils samples. For engineering purposes, soils may be classified by the following systems:

- Particles size classification system
- Texture classification system
- Unified soil classification system
- IS classification system

III. PARTICLE SIZE CLASSIFICATION SYSTEM

In this system, soils are arranged according to their grain size. The size of individual particles has an important influence on the behaviour of the soils. It is a general practice to classify the soils into four broad groups, namely, gravel, sand, silt size and clay size. The behaviour of fine-grained soils depends upon the plasticity characteristics and not on the particle size. While classifying the fine-grained soils on the basis of particles size, it is a good practice to write silt size and clay size, and not just silt and clay.

In general, the term silt and clay are used to denote the soils that exhibit plasticity and cohesion over a wide range of water content. The soil with clay size particles may not exhibit the properties associated with clays such as rock flour has particles of the size clay particles but does not possess plasticity. It is classify as clay size and not just clay in the particles size classification system.

Classification based only on particle size may misleading for fine-grained soils because the behaviour of such soils depends on the plasticity and not on the particle size. However classification based on particles size is of immense value in the case of coarse-grained soils, since the behaviour of such soils depends mainly on the particle size.

These are various grained size classification in use, but the more commonly used systems are:

- US bureau of soil classification and public road administration (PRA) system of United States.
- International soil classification proposed at the international soil congress Washington, D.C, 1927.
- M.I.T. classification proposed by prof. Gilboy of Massachussets Institute of Technology as a simplification of the Bureau of soils classification.
- Indian standard classification (IS1498-1970) based on the M.I.T classification system.

3.1 US BUREAU OF SOILS CLASSIFICATION SYSTEM

This is one of the earliest classification system developed in 1985 by US Bureau of soils. In this system the soils are divided into four groups:

- Gravel - particles size greater than 1.0mm.
- Sand – particle size between 0.05mm to 1.0mm
- Silt size – particle size between 0.005mm to 0.05mm
- Clay size – particles size smaller than 0.005mm

Clay Size	Silt Size	Sand				Fine Gravel	Gravel
		Very Fine	Fine	Medium	Coarse		

0.005 0.05 0.01 0.25 0.5 1.0 2.0 mm

Fig. 1: US Bureau of soils classification system

3.2 INTERNATIONAL CLASSIFICATION SYSTEM:

This system was known as the Swedish classification system before it was adopted as International system. However, the system was not adopted by the United States. In this system, in addition to sand, silt and clay, a term Mo (majla) has been used for soil particles in the siz range between sand and silt-size.

Ultra Clay	Clay		Silt		M_o		Sand				Gravel
	F	C	F	C	F	C	F	M	C	VC	

0.0002 0.0006 0.002 0.006 0.02 0.05 0.1 0.2 0.5 1.0 2.0 mm

Fig. 2 : International classification system

3.3 M.I.T CLASSIFICATION SYSTEM:

In this system, the soil is divided into four groups:

- Gravel - particles size greater than 2mm.
- Sand – particle size between 0.06mm to 2mm
- Silt size – particle size between 0.002mm to 0.06mm

- Clay size – particles size smaller than 0.002mm (2μ)

It is noted that MIT system used only two integer 2 and 6, and easy to remember. The naked eye can see the particles size of about 0.06mm and larger. Important changes in the behaviour of soil occur if particle size is larger than 0.06mm when it behaves as cohesionless soil.

	Silt Size			Sand			
Clay Size	F	M	c	F	M	C	Gravel

0.002 0.006 0.02 0.06 0.2 0.6 2.0 mm

Fig. 3 : M.I.T. Classification System

Indian standard classification:

		Sand			Gravel			
Clay Size	Silt Size	F	M	C	F	C	Fine Gravel	Gravel

0.002 0.075 0.425 2 .0 4.75 20 80 300 mm

Fig. 4: Indian Standard Classification System

IV. TEXTURAL CLASSIFICATION

The triangular classification system suggested by US Bureau of Public Roads Administration is commonly known as the textual classification as shown in fig. 5. This classification is based on the particle size only. As the properties of clayey soils are less dependent on the particle size distribution. Hence this classification is more suitable for coarse-grained soils.

The visual appearance of a soil is called its texture. It depends upon the particle size, shape of particles and gradation of particles. The term texture is used to express the percentage of the three constituencies of soils, namely, sand, silt size and clay size. According to the textural classification, the percentage of sand (particle size 0.05 to 2.0mm), silt size (0.005 to 0.05mm) and clay size (<0.005mm) are plotted along the three sides of an equilateral triangle. The equilateral triangle is divided into 10 zones, each zone giving a type of soil.

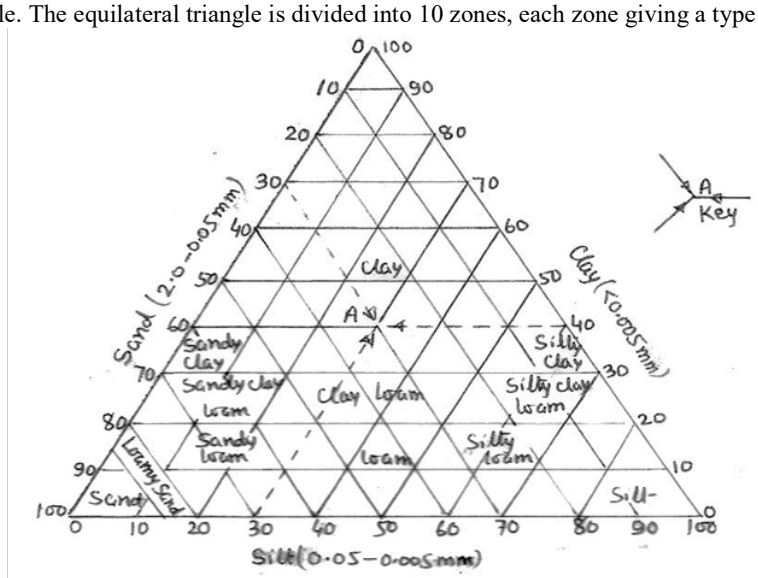

Fig. 5: Textural Classification Chart

For given percentage of the three constituents forming a soil, lines are drawn parallel to three sides of the equilateral triangle as shown by arrows in the key as shown in Fig. 5 For example, if a soil consists of 30% sand, 30% silt size and 40% clay size, then the three lines so drawn intersect at the point A situated in the sector designated as clay. Hence a soil will be term as clay size.

The texture classification system assumes that the soil does not contain particles larger than 2.0mm size. However, if the soil contains a certain percentage of soil particles larger than 2.0mm, a correction is required in which the sum of the percentage of sand, silt size and clay size is increased to 100%. For example, if a soil consists of 30% of particles larger than 2mm, sand 7%, silt size 14% and clay size 49%, then the corrected % of sand, silt size and clay size are obtained by multiplying with a factor of 100/70. Therefore, the corrected % of sand, silt size and clay size are 10%, 20% and 70% respectively and is shown by point Q in the Fig. 5. The point falls in the zone designated as clay. Hence soil is classified as clay.

V. UNIFIED SOIL CLASSIFICATION SYSTEM (USCS)

The Unified Soil Classification System is based on the airfield classification that was developed by Casagrande during World War II. This system was adopted jointly by Corps of Engineers, US army and the US Bureau of Reclamation in 1952. It is based on both grain size and plasticity properties of the soil. The system is the most popular system for use in all types of engineering problems involving soils.

According to USCS, the coarse-grained soils are classified on the basis of their grain size distribution and the fine-grained soils (whole behaviour is controlled by plasticity) are classified on the basis of their plasticity characteristics.

All soils are classified into four major groups:

- Coarse-grained.
- Fine-grained.
- Organic soil.
- Peat.

Coarse-grained soils: if more than 50% of the soil is retained on 75µ sieve (200 ASTM), it is designated as coarse-grained soils.

If 50% or more of the coarse fraction is retained on 4.75µ sieve are designated as gravel (G) otherwise they are designated as sand (S).

Both gravel and sand are subdivided into four sub groups:

- Well graded (W).
- Poorly graded (P).
- Non-plastic fines (M).
- Plastic fines (C).

Coarse-grained soils may be well graded (W) or poorly graded (P) [either uniformly graded or gap graded] depending upon the Cu and Cc.

Fine-grained soil: If more than 50% of the soil passing 75µ sieve. It is designated as fine-grained soil.

Organic soil: Organic soils contain a significant proportion of dispersed vegetable matter. The organic matter in soil is due to disintegrated plant roots and other vegetable matter such as muck or more fibrous matters. It can be easily identified by its colour, odour and fibrous nature.

Oven- drying method is used to distinguish between organic and inorganic soils. If weight of the soil decrease by 30% or more, it is classified as organic or otherwise it is classified as inorganic.

Highly organic soil: highly organic soils are fibrous in nature and having high compressibility, usually peat and swelling soils are not subdivided, but put into one group only with group symbol Pt.

Fine-grained soils are divided into three groups:

- Inorganic silt and very fine sand (M)
- Inorganic clay (C)
- Organic silt and clay (O)

Fine-grained are further subdivided into two subgroups based on the liquid limit of the soil:

- Silts and clays of low compressibility w_L<50%.
- Silts and clays of high compressibility w_L>50%.

TABLE 1 : SYMBOLS USED IN USC SYSTEM

Soil type (main group)	**Prefix (symbol)**	**Subgroup**	**Suffix (symbol)**
Gravel	G	Well graded	W
Sand	S	Poorly graded	P
Silt	M	Non-plastic fines	M
Clay	C	Plastic fines	C
Organic	O	Low plasticity	L
Peat	Pt	High plasticity	H

If the coarse-grained soils are well graded with less than 5% fines, they are given the symbol GW and SW, if poorly graded (P), symbols GP and SP.

If the coarse-grained soils contain more than 12% fines, they are designated as GM, GC, SM or SC. If the % of fines is between 5% to 12%, dual symbols such as GW-GM, SP-SM are used.

Plasticity chart: Casagrande developed a chart useful for identifying fine- grained soils. It is a relationship between liquid limit and plasticity index. This chart is adopted by USCS system as shown in Fig.6.

A line called A-line is drawn diagonally across the chart. The area below A-line represents inorganic silt and organic soil, and above A-line represents inorganic clay. The equation of A-line is:

$I_p = 0.73\ (w_L - 20)$

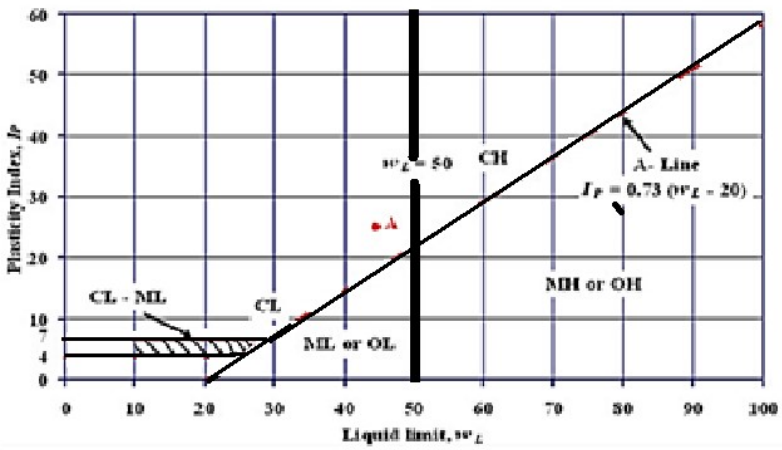

FIG.6: PLASTICITY CHART OF USCS

Fine-grained soils are designated as ML, OL, CL (low plasticity) and MH, OH, CH (high plasticity). Soil possessing the characteristics of more than one-group are termed as boundary soils and are designated by dual group symbols.

VI. INDIAN STANDARD SOIL CLASSIFICATION SYSTEM

The Indian Standard Soil Classification (IS: 1498-1970) is basically the same as that of the Unified Soil Classification System (USCS) but for a slight modification in the plasticity chart. There is one basic different in the classification of fine-grained soils. The fine-grained soils in ISC system are subdivided into three categories of low (w_l<35%), medium (35%<w_l< 50%) and high compressibility (w_l>50%) instead of two categories of low and high compressibility in USCS system.

Fig. 7 represents the plasticity chart as adopted by the Indian Standard Soil Classification system. Highly organic soils (i.e. peat) are classified as Pt.

TABLE: 2. SYMBOLS USED IN ISSC SYSTEM

Soil type (main group)	**Prefix (symbol)**	**Sub group**	**Suffix (symbol)**
Gravel	G	Well graded	W
Sand	S	Poorly graded	P
Silt	M	Non-plastic fines	M
Clay	C	Plastic fines	C
Organic	O	Low plasticity (w_l<35%) Medium plasticity (35%<w_l<50%)	L I
Peat	Pt	High plasticity (w_l>50%)	H

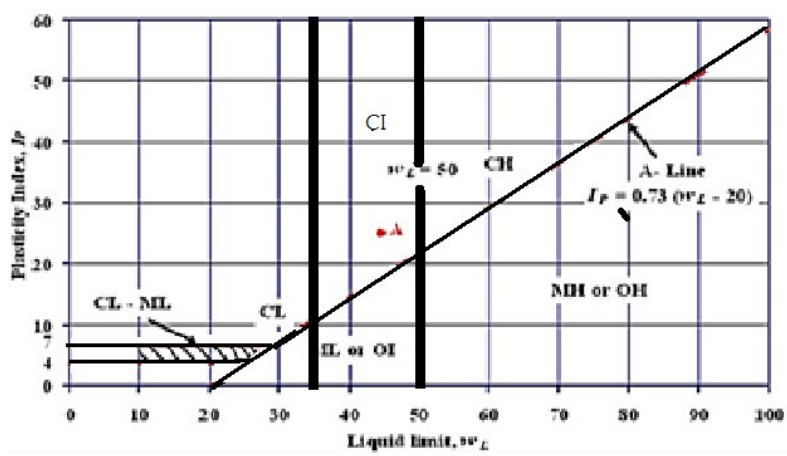

FIG.7 : PLASTICITY CHART OF ISSCS

VII. BOUNDARY CLASSIFICATIONS

The classification of coarse-grained soil is done on the basis of their grain and gradation characteristics. When the fines (<75μ) present in them are less than 5%, then it is classified as GW or SW (GP or SP).

Coarse-grained soils which contain more than 12% fine are classified as GM or SM, if the fines are silty (i.e. lies below the A-line on the plasticity chart). They are classified as GC on SC, if the fines are clayey (i.e. lies above the A-line).

Coarse-grained soils having 5% to 12% fines are boarder line cases and given a dual symbol. The first part of the dual symbol is indicative of the gradation, while the second part indicates the nature of fines. For example SW - SC is well graded sand with clay fines.

There are no rigid boundaries between soil groups. A soil may possess characteristic of two groups either in grain size distribution or in plasticity. In such cases, boundary classifications occur and dual symbols are assigned.

BOUNDARY CLASSIFICATION FOR COARSE-GRAINED SOILS

a. Boundary classification within gravel group or sand groups.

GW-GP, GM-GC, GW-GM, GW-GC, GP-GM.

SW-SP, SM-SC, SW-SM, SW-SC, SP-SM.

While assigning dual symbols, first write a coarser soil than a finer soil.

b. Boundary classification between the gravel and sand groups.

GW-SW, GP-SP, GM-SM, GC-SC.

Example: a gravel with 10% fines, C_u=12, C_c=1.5 and Ip = 6 will be classified as GW-GM (not GW-GC).

BOUNDARY CLASSIFICATION FOR FINE-GRAINED SOILS

It the w_L and Ip values fall close to the A-line, the w_L is very close to 35% or 50% or Ip between 4 and 7 shall be assigned dual symbols.

a. Within the same compressibility:

ML-CL, ML-OL, CL-OL, CI-MI, MI-OI, MH-CH, MH-OH, CH-OH.

First write a coarse soil and then a finer soil.

Between low and medium plasticity:

ML-MI, CL-CI, OL-OI.

Between medium and high compressibility:

MI-MH, CI-CH, OI-OH.

BOUNDARY CLASSIFICATION BETWEEN COARSE-GRAINED OR FINE-GRAINED SOILS:

SM-ML,

VIII. CLASSIFICATION OF SOILS BASED ON THE COMPONENTS OF THE SHEARING RESISTANCE

(i) ϕ – Soils: These are called cohesionless soil. In ϕ-soils, c=o.
Example: Sands and gravels (i.e. coarse grained soils).

(ii) C – Soils: These are called cohesive soil. In c-soils, ϕ=o.

Example: clays (i.e. fine-grained soils).

(iii) C – ϕ Soils: These are called cohesive and frictional soils like silts.c

IX. CORRELATION BETWEEN N AND ϕ° FOR A COHESIONLESS SOIL

ϕ° = 0.3N + 27 or $\phi^{\circ} = \sqrt{20N} + 15$

X. CORRELATION BETWEEN N AND SOIL PROPERTIES

Table 26.1 and 26.2 give some empirical correlations of the soil properties with corrected N Values.

Table 3.0

Values of γ, I_D and ϕ for cohesionless soils based on the corrected N- Value

N-Value	ϕ degree	Relative of Density I_D %	Nature of Soil (Denseness)	Unit weight of soil γ t/m^3
<4	25 – 28	< 15	Very loose	1.12 – 1.60
4 – 10	28 – 30	15 – 35	Loose	1.44 – 1.84
10 - 30	30 – 36	35 -65	Medium	1.76 – 2.08
30 - 50	36 – 42	65 – 85	Dense	1.76 -2.24
>50	>42	>85	Very dense	2.08 – 2.04

Meyerhof's Correlation

$\phi = 25 + 0.15 I_D$ With fines >5%

$\phi = 30 + 0.15 I_D$ With fines <5%

Large values should be used for granular soil with 5% or less fine sand and silt

Table: 4.0

Value of unconfined compressive strength of cohesive soils based on corrected N – value

N - value	Nature of soil (Consistency)	Unconfined compressive strength q_u KN/m^2
0 - 2	Very soft	< 25
2 - 4	Soft	25 – 50
4 – 8	Medium	50 – 100
8 - 16	Stiff	100 – 200
16 - 32	Very stiff	200 – 400
>32	Hard	>400

Note : $q_u = \frac{N}{8} kg/cm^2 = \frac{100N}{8} KN/m^2$ = 12.5N KN/m^2 for $I_D < 30$

$q_u = \frac{N}{10} kg/cm^2 = \frac{10N}{m^2} \frac{KN}{}$, for $I_D > 30$

11.0 Measured N-Values need some corrections before their use in empirical equations

- Overburden pressure correction
- Dilatancy correction

11.1 OVERBURDEN PRESSURE CORRECTION:

In coarse-grained soils, the overburden pressure affects N- Value. If two soils having same relative density but different confining pressure are tested, the one with a higher confining pressure gives a higher N-value. As the confining pressure in cohesionless soils increases with the depth, the N-value of soil at shallow depths is under estimated and that at greater depths is overestimated.

For uniformity, the N-values obtained from field tests under different effective overburden pressure are corrected to a standard effective overburden pressure.

Gibbs and Holtz (1957) recommended for dry or merit sand

Ne = N_R X $\frac{280}{\sigma_0+70}$ when N_R = Recorded N- value

Ne = Corrected N-value for overburden pressure correction

σ_0 = affective overburden pressure KN/m^2

σ_n= Normalising factor=$\frac{280}{\sigma_0+70}$

$\sigma_0 \leq 280\ KN/m^2$(Referece pressure)

$\sigma_n$should be 0.45 to 2 . if C_n is greater than 2, Ne should be divide by 2

Peck, Hansen and Thornburn (1974)

Ne = 0.77 $N_R \log\left(\frac{2000}{\sigma_0}\right)$ for $\sigma_0 \geq 24 KN/m^2$

N_e at $\sigma_0 = 0, N_e = 2$

Peck and Bazarra (1969)

$N_e = \frac{4N_R}{1+0.0418\sigma_0} \sigma_0 \leq 71.8\ KN/m^2$

$N_e = \frac{4N_R}{1+0.0104\sigma_0} \sigma_0 = 71.8 KN/m^2$

$N_e = N_R$ When $\sigma_0 = 71.8 KNm^2$

Murthy

$N_e = \frac{4NR}{2+0.014\sigma_0}$ For $\sigma_0 \leq 25 KN/m^2$

$N_e = \frac{4NR}{2+0.0500} \sigma_0 > 25 KN/m^2$

11.2 DILATANCY CORRECTION

Terzaghi& Peck,

for Ne > 15, N= $15+\frac{1}{2}(N_E - 15)$

The average value of corrected N- value upto 2B is determined. In computing the average any individual value more than 50% of the average should be neglected. But the values for all loose seams should be included.

XII. DETERMINATION OF BEARING CAPACITY

Teng (1962) proposed correlation between N and net ultimate bearing capacity for shallow foundations in cohesionless soils:

12.1 FROM BEARING CAPACITY CONSIDERATIONS

For strip footings

$$q_{nult} = \frac{1}{62}[3N^2BR\omega_1 + 5(100+N^2)DR_w]t/m^2$$

For square and circular footings

$$q_{nult} = \frac{1}{31}[N^2R_{w_1} + 3(100+N^2)DR_w] \qquad t/m^2$$

$$q_{safe} = \frac{qnult}{Fs} + \gamma D$$

12.2 FROM SETTLEMENT CONSIDERATIONS

$$q_{safe} = 14(N-3)\left(\frac{B+0.3}{2B}\right)^2 R\omega_1 C_D S_p \, t/m^2 \quad for\ any\ settlement$$

$$where\ q_{nult}, q_{safe}\ in\ t/m^2$$

D and B in m

N = corrected SPT Value

R_w, R_{w_1} = water table correction factors

C_D = correction factor for depth of embedment

$$= 1 + \frac{D}{B} \leq 2$$

Similary Meyerhof'S correlation between N and q_{safe}

$q_{safe} = 1.22NK_{D_1}$ for $B \leq 1.2m$

$q_{safe} = 0.81NK_{D_2}(\frac{B+0.3}{B})^2$ for B > 1.2m and for 25mm settlement

where q_{safe} in t/m^2

B in m

$$K_{D_1} = 1 + 0.2\frac{D}{B} \leq 1.2$$

$$K_{D_2} = 1 + 0.33\frac{D}{B} \leq 1.33$$

q_{all} for other permissible settlement

$$(q_{safe}) = q_{safe} \times \frac{S_t}{25}$$

CONCLUSIONS

a. N- Value increases, void ratio decreases and relative density and bearing capacity of foundations increases.

b. The N- values give a good indication of the denseness of the granular soil deposits.

c. It is extremely difficult to get undisturbed soil samples in sand deposits. Hence N- values are always relied on the determination of the relative density of coarse –grained soils.

d. The reliable values of angle of internal friction ϕ are determined from correlation between N and ϕ

e. Teng's correlation between corrected mean value of N and q_{nult}, q_{safe} and q_{all} for shallow foundation is one of the most and reliable methods for coarse – grained soils.

f. In- situ test result (N-values) are commonly used to estimate the total settlement of foundations founded on granular soils. The allowable bearing capacity of granular soils is governed more by consideration of settlements than bearing failure consideration.

g. Silt with N-value less than 10 are loose. Loose silt is unsuitable as bearing materials due to large settlement. Medium to dense silts, if non –plastic behave like fine sands and if plastic, behave like clays.

h. Special attention should be made about foundations in saturated sands with ≤ 5 . Such soils show rapid subsidence with change of W.T. when loaded. In such cases, either the sand deposits should be compacted or the foundations should be founded on piles. All sands with $N < 10$ are to be consider as loose $(\phi \leq 30^\circ)$.

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