Bearing Capacity Estimation for Shallow Foundations Based on Standard Penetration Test

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Abstract: For design and construction of any infrastructure in-situ geotechnical tests are must and provide vital information and data. There are various insitu-tests for estimation of engineering properties of soil and its bearing capacity. The Standard Penetration Test (SPT) is one of the oldest and most commonly used insitu tests worldwide. In India normally any soil investigation and boring program is not considered complete without SPT. Various researchers have suggested various correlations to estimate safe bearing capacity or allowable soil pressure for shallow foundations on the basis of SPT values. This paper presents the brief review of such commonly used correlations and proposes a new correlation to estimate allowable soil pressure for isolated footings.

Keywords: Penetration tests, Standard Penetration Test, Allowable Soil Pressure, SPT values

1 INTRODUCTION

Pushing or driving by hammer a steel rod, pipe or such other object into the ground to determine the resistance to penetration is commonly referred as sounding. A variety of sounding devices commonly known as pentrometers are used for this purpose. If the device is pushed into the ground it is known as static and if it is driven by hammering it is known as dynamic.

The pentrometer measure the resistance to pushing or driving of the object and this is then interpreted in terms of geotechnical characteristics of soil. The pentrometers are used to determine the density index of cohesionless soil and consistency of cohesive soils, bearing capacity etc. by correlating these and other desired properties with resistance of penetration. The value of such tests lies in the amount of experience behind them. The penetration tests are useful for general exploration of erratic soil profiles, for finding depth to bed rock or hard stratum, and to have an approximate indication of the strength and other properties of soils, particularly the cohesionless soils, from which it is difficult to obtain undisturbed samples.

A large number of penetration techniques are used. In-situ penetration tests have been widely used in geotechnical and foundation engineering for site investigation in support of analysis and design. While the Standard Penetration Test (SPT) is carried out in a borehole, Static Cone Penetration Test (SCPT) and Dynamic Cone Penetration Test (DCPT) are y carried out without a borehole. All the three tests measure the resistance of the soil strata to penetration by a pentrometer. Useful empirical correlations between penetration resistance and soil properties are available for use in foundation design. This paper presents in brief conduct of SPT, factors affecting SPT values and required corrections, SPT and consistency of soils and then reviews various suggested formulas to estimate safe bearing capacity of shallow foundations on the basis of SPT values.

2 STANDARD PENETRATION TEST

One of the most common in-situ tests is the standard penetration test or SPT. This test which was originally developed in the late 1920s is currently the most popular and economical means to obtain subsurface information (both inland and offshore). It offers the advantage of low cost, applicability to many soil types, samples are obtained (although disturbed) and a large database from which many useful correlations have been developed. The standard penetration test commonly referred as SPT is used extensively in soil exploration programmes and is most commonly conducted test in India. The SPT test is governed by IS-2131[1]. The test consists of driving a standard split spoon sampler, 50.8 mm outside diameter and 35 mm inside diameter, into soil under the blows of a drop weight of 65 kg falling freely through 75 cm. IS: 9640 [2] provides the specifications for the same. The number of blows required for 30 cm penetration of sampler in the soil is designated as N value and is termed as standard penetration blow count. The test setup consists of drilling equipment, casing or drilling fluid system, split spoon sampler, drive weight assembly etc. The other accessories consist of lifting rail, tongs, rope, screw jack etc. A typical schematic diagram and equipment for SPT is presented in Figure 1. In India a soil investigation report or a bore log is not considered complete if it does not contain N values.

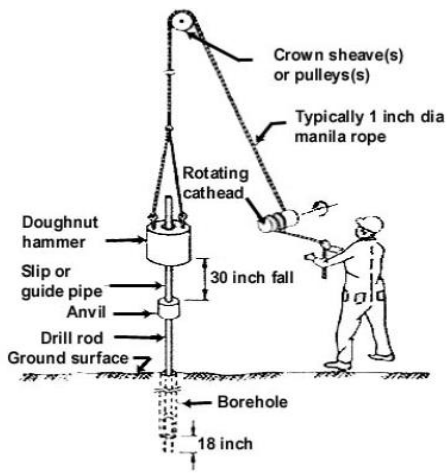

Figure1: Schematic Diagram for SPT

Normally, test is conducted at interval of 1.5 m. Tests shall be made at every change in stratum or at intervals of not more than l.5 m whichever is less. Tests may be made at lesser intervals if specified or considered necessary. The intervals may be increased to 3 m if in between vane shear test is performed.

3 FACTORS AFFECTING SPT VALUES

There are various variables/ factors/ parameters such as Weight of Hammer, Height of drop Free fall, Eccentricity of blows, Cushion, Rate of application of blow, Size of connecting rod, Depth of boring, Drive Shoe, Counting blows, Sludge at the test level, Hydrostatic head, particle size, Very fine silty sand below ground water table, Overburden Pressure etc. affecting the results of SPT.

It is necessary that errors resulting from variation in these variables are kept to minimum and that the test is executed in a standard manner. Only then statistical correlations obtained can be more meaningfully applied.

4 CORRECTION TO OBSERVED N VALUES

In routine tests corrections to observed value of N are made for two parameters namely dilatancy and overburden pressure

4.1 Correction for Dilatancy

The N-values of SPT as measured in field are corrected for dilatancy if test us conducted in fine or silty, saturated sand and when the recorded blow count is greater than 15. This correction as recommended by Terzaghi and Peck [3] is given in equation 1 in which N’’ and N' are corrected and actual blow counts respectively.

$$N'' = 15 + (N' - 15) \quad (1)$$

4.2 Correction for Overburden Pressure

The correction for overburden pressure is applied only to cohesionless soils (dry, moist or wet). The Correction for dilatancy also referred as saturation effect as given in equation is applied prior to overburden correction. The correction for overburden pressure as suggested by Gibbs and Holtz [4] is given in Equation 2 in which $\square_o$ is effective overburden pressure in t/m^2.

$$N = 35N''/(\square_0+7) \quad (2)$$

5.0 SPT and Consistency of Soils

The various correlations are proposed by various workers relating N-values to relative density and other properties of cohesionless soils. Correlations are also available relating N with the unconfined compressive strength of cohesive soils. Attempts have also been made to correlate compressibility of soils and its bearing capacity to N-values.

5.1 Cohesionless Soil

The consistency of a granular soil is indicated by its relative density (D_I) as a function of N values is presented in Table 1. This table also provides the values of angle of internal friction (ϕ) and soil density (γ)

Table 1: SPT and Properties of Cohesionless Soils

N	Description	D_I, %	ϕ, Deg.	γ, t/m^3
`0-4	Very Loose	0-15	25-30	1.10-1.60
4-10	Loose	15-35	27-32	1.45-1.85
10-30	Medium	35-65	30-35	1.75-2.10
30-50	Dense	68-85	35-40	1.75-2.25
>50	Very Dense	85-100	38-43	2.10-2.40

The relationship between ϕ an N values as provided in The IS: 6403 [5] provides a graphical correlationship between ϕ and N values from which one can obtain value of ϕ for cohesionless soils. Once the value of ϕ is known one can obtain bearing capacity factors N_c, N_q and N_{γ} and the can estimate bearing capacity using appropriate bearing capacity equation.

5.2 Cohesive Soils

The consistency of a cohesive soil is indicated by its unconfined compressive strength (q_u). The relationship between N values of SPT and consistency, as proposed by Terzaghi and Peck [2], is presented in Table 2 and is very widely used.

Table 2: SPT and Properties of Cohesive Soils

N	Consistency	q_u, kN/m^2
0-2	Very Soft	<25
2-4	Soft	25-50
4-8	Medium	50-100
8-15	Stiff	100-200
15-30	Very Stiff	200-400
>30	Hard	>400

The relation between cohesion (c_u); which is half the unconfined compressive strength (q_u) can be obtained from Equation 3.

$$c_u\ (kN/m^2) = 6.54N \qquad (3)$$

This relationship given in Equation 3 provides very reasonable result except for very stiff to hard clays. Particularly for hard clays, value of C_u obtained is found to be on lower (conservative) side. For such soil it may range from 10 to 20 times of N.

6 ESTIMATING SAFE BEARING PRESSURE

The N value is commonly used to determine various spoil properties and also to estimate allowable soil pressure, settlement calculations and also for estimation of pile capacity. In India SPT is most common penetration test. The soil investigation report and bore log is not considered without N values.

In literature various correlations are proposed to estimate allowable bearing pressure of soils, settlement, safe pile capacity, pile socket resistance etc. Such approaches to correlate penetration resistance to design parameters can be and are subjects of criticisms. But, past experiences indicate that SPT can provide reliable and safe design parameters when used with caution keeping in mind the limitations of the test and its application.

The analytical methods for the determination of bearing capacity of footings are based essentially on shear failure. However, permissible settlements play an important role in determining the safe bearing capacity. The safe bearing pressure or allowable soil pressure (q_a) for specified settlements is the intensity of loading which causes a permissible or specified settlement (ρ) of the foundation. In literature various correlations between SPT values and safe bearing capacity from shear consideration as well as allowable soil pressure based on allowable or tolerable settlement are reported. Some such commonly used correlations are examined in the following.

Terzaghi and Peck [2] proposed empirical charts giving relationship between allowable bearing pressure and N values, for a permissible settlement of 25 mm based on the assumption that water table is at a depth of at least B below foundation level. This relationship limits the maximum settlement of individual footing to 25 rnm and a differential settlement of 20 mm, assuming that a differential settlement of 20 rnm can be tolerated by most of the ordinary structures.

On the basis of data available from literature it was observed that five such correlations proposed by Terzaghi and Peck [3], Tang [6], Mayerhof [7], Peck, Hanson and Thornburn [8] and Bowles [9] are commonly adopted. These five commonly used correlations of allowable soil pressure based on tolerable settlement of 25 mm for isolated footings are presented in Equation 4a to Equation 4e respectively.

$$q_a = 3.35*(N-3)*B_{T1}*R_{w2}*C_{d1} \qquad (4a)$$

$$q_a = 3.5*(N-3)*B_{T1}*R_{w2}*C_{d1} \qquad (4b)$$

$$q_a = 0.81*N*B_{T2}*R_{w2}C_{d2} \qquad (4c)$$

$$q_a = 1.1*N*R_{w2}*C_{d2} \qquad (4d)$$

$$q_a = 1.25*N*B_{T2}*R_{w2}C_{d2} \qquad (4e)$$

In Equation 4 R_{w2} is water reduction factor and C_{d1} and C_{d2} are depth factors. the term B_{T1} and B_{T2} are as given in Equation 5a and 5b respectively.

$$B_{T1} = [(B+00.3)/2B]^2 \qquad (5a)$$

$$B_{T2} = [(B+00.3)/B]^2 \qquad (5b)$$

While using any of the above correlations it is preferable to use value of N as average corrected value determined below base of the footing up to 1.5 to 2.0 times the width of footing at every 75 cm. Although the correlations given in Equation 4 are more appropriate for cohesionless soils; they are also used for cohesive soils sometimes with come corrections/modifications/changes.

When above correlations are applied to a particular case it is observed that value of allowable soil pressure (q_a) obtained are different. For example for a square footing of 1.5m x1.5 m, placed at a depth of 1.5 m with water table at the base of footing and average corrected value on N = 15 for sandy soil provides the values as given in Table 3.

Table 3: Sample Values of q_a

Correlation Proposed by	q_a, t/m^2
Terzaghi & Peck (1948)	22.7
Mayerhof (156)	16.9
Bowles (1982)	26.1
Peck, Hanson & Thornburn (1974)	16.0
Tang (1962)	22.7
Average Value	19.1

It can be seen from data given in Table 3 that for sandy soil predicted allowable soil pressure ranges from 16.0 to 26.1 t/m2 with average value of 19.1 t/m^2. It can further be seen that values predicted by Peck, Hanson & Thornburn [9] correlation provides the minimum values while those predicted by correlation given by Bowles [10] provides maximum values which are about 1.6 times that predicted by Peck, Hanson & Thornburn [9] correlation. Thus if one uses Peck, Hanson & Thornburn [9] correlation then values seems to be too conservative, while if one uses Bowles [10] correlation then sometimes it may lead to little risky situation. In view of above for real practice it is recommended that it is safe and rational to use the average value of allowable soil pressure obtained by five correlations given in Equation 4.

7 PROPOSED CORRELATION EQUATION

However in such a case one is required to use all five correlations and then obtain average value. In view of this in the following an attempt is made to develop a new correlation directly providing average value of q_a. A close examination of 5 correlations given in Equation 4 indicate that these correlations consist of 4 terms.

$q_a = N_T*B_T*R_T*D_T$ (6)

Term N_T consists of N value, term B_T consist of B value, term R_T consist of water reduction factor and term 4 D_T consist of depth factor.

The water reduction term (R_T) is there in all five correlations and its minimum value is prescribed as 0.5. Thus we may adopt R_T as 0.50.

The depth term (D_T) is there in all 5 correlations. While maximum value of C_{d1} (1+D/B) is 2.0; that of C_{d2} (1+0.33D/B) is 1.33. Practically we use isolated footing having width ranging from 1 m to 4 m. Further normally the depth of footing also ranges from 1 m to 4 m. The equation for C_{d1} and C_{d2} indicate that if depth of footing is more than width of footing then the values of depth factor reaches to their respective maximum values. The term C_{d1} appears in 2 correlations and term C_{d2} appears in 3 correlations. Thus maximum weighted value of depth term is (2*2 + 1.33*3)/5 = 1.60. Thus we may adopt value of D_T as 1.60.

The width term B_T appears in 4 correlations. While two correlations have B_{T1} other two have B_{T2}. A close examination of these indicates that term B_{T2} is four times of termB_{T1}. Thus for analysis the B_{T1} term is converted to B_{T2} by multiplying it with 4 and this is adjusted by dividing the N term in these correlations by 4. The value of term B_T for footing width ranging from minimum of 1.0 m to maximum of 6.0 m ranges from 1.69 to 1.10 with average value of 1.27. Thus the Peck, Hanson & Thornburn [9] correlation which does not have width term can be considered as having the width term as unity.

Thus for analysis B_T is equal to $[(B+0.3)/(B)]^2$. Further this term can be approximated to (1+0.6/B). For footing width ranging from minimum of 1 m to maximum of 6 m, the error in this approximation ranges from 0.2% to 5.5% with average of 1.5%.

Now the most important N term (N_T) for 5 correlations are 0.8375*(N-3), 0.875*(N-3). 0.81*N, 1.1*N and 1.25*N. Neglecting the -3 from first two; the average N_T works out to be 0.975N. Thus

$q_a = 0.975N*(1+0.6/B)*0.50*1.60$

$q_a = 0.78N*(1+0.6/B)$ (7)

The values of q_a obtained from above proposed Equation 6 were compared with the average values obtained from Equation 4 and accordingly the Equation 7 is at arrived at.

$q_a = 0.7N*(1+0.6/B)-1$ (8)

The values of q_a obtained by Equation 8 for range of B from 1 m to 6 m and N values ranging from 10 to 50 are observed to be very close to the average value of q_a obtained from 5 correlations given in Equation 4. The typical values for footing width of 1, 2, 3 and 4 m are presented in Table 4.

Table 4a: Average and Predicted Values of q_a (t/m^2) for B = 1.0 m

N	For B=1.0 m		For B=2.0 m		For B=3.0 m	
	Average q_a	Predicted q_a	Average q_a	Predicted q_a	Average q_a	Predicted q_a
10	10.15	10.20	8.26	8.10	7.68	7.40
15	16.09	15.80	13.07	12.65	12.14	11.60
20	22.03	21.40	17.87	17.20	16.60	15.80
25	27.97	27.00	22.68	21.75	21.06	20.00
30	33.91	32.60	27.49	26.30	25.52	24.20
35	39.85	38.20	32.30	30.85	29.99	28.40
40	45.79	43.80	37.10	35.40	34.45	32.60
45	51.73	49.40	41.91	39.95	38.91	36.80
50	57.67	55.00	46.72	44.50	43.37	41.00

N	For B=4.0 m		For B=5.0 m		For B=6.0 m	
	Average q_a	Predicted q_a	Average q_a	Predicted q_a	Average q_a	Predicted q_a
10	7.40	7.05	7.24	6.84	7.68	7.40
15	11.69	11.08	11.43	10.76	12.14	11.60
20	15.99	15.10	15.63	14.68	16.60	15.80
25	20.28	19.13	19.82	18.60	21.06	20.00
30	24.57	23.15	24.01	22.52	25.52	24.20
35	28.87	27.18	28.21	26.44	29.99	28.40
40	33.16	31.20	32.40	30.36	34.45	32.60
45	37.45	35.23	36.60	34.28	38.91	36.80
50	41.75	39.25	40.79	38.20	43.37	41.00

It can be seen from data given in Table 4 that the value of q_a predicted from proposed correlation Equation 8 closely matches with the average values of q_a obtained from the five correlations given in Equation 4.

In general the factors in Equation are adjusted such that the predicted values in all cases are 0% to 7% (with average of 4%) lower than average values obtained from 5 correlations.

8 CONCLUSIONS

The paper discusses commonly used correlations for obtaining q_a on the basis of N values and proposes a new simple and safe correlation to predict q_a. The major conclusions of study are

(1) This paper presents a summary of correlations available correlations for prediction of q_a based on N values and proposes a new correlation (Equation 8) providing the q_a corresponding to average value obtained from 5 commonly used correlations (Equation 4).

(2) The proposed correlation equation provides value of q_a which matches very closely with the average value obtained by 5 commonly used correlations.

(3) The proposed equation The proposed equation inbuilt considers the effect of water table and depth factor consideration.

(4) The proposed correlation is based on consideration of D = B. If D > B it does not make any change in q_a values. On the other hand if D < B; the predicted values of q_a are on safer side.

REFERENCE

[1] IS: 2131 (1997), Method of Standard Penetration Test for Soils. BIS, New Delhi.

[2] IS: 9640 (1980), Specification for Split Spoon Sampler. BIS, New Delhi.

[3] Terzaghi and Peck (1967), Soil Mechanics in Engineering Practice John Wiley and Sons, New York.

[4] Gibbs H. J and Holtz W. G. (1957), "Research on Determining the Density of Sands by Spoon Penetration Test", Proc. 4th Int. Conf. Soil Mech. & Found. Eng., Vol. 1, p. 35-39.
[5] IS: 6403(1981), Code of Practice for Determination of Bearing Capacity of Shallow Foundations. BIS, New Delhi.
[6] Tang C. Y. (1992), Foundation Design. Prantice-Hall of India, New Delhi.
[7] Mayerhof G. G., (1956), "Penetration Tests and Bearing Capacity of Cohesionless Soils", Jnl. Soil Mech. & Found. Div., ASCE, Vol. 82, No. 1.
[8] Peck R. B., Hanson W. E. and Thornburn T. H. (1974), Foundation Engineering. John Wiley and Sons, New York.
[9] Bowles J. E. (1988), Foundation Analysis and Design. McGraw-Hill Book Company, New Delhi.