

L5/P1

Field Tests / In-situ Tests

Standard Penetration Test
 Vane Shear Test
 Cone Penetrometer Test
 Pressuremeter Test
 Dilatometer Test
 Dynamic Penetration Tests (DPL, DPM, DPH, DSPH)

1

Standard Penetration Test (SPT)

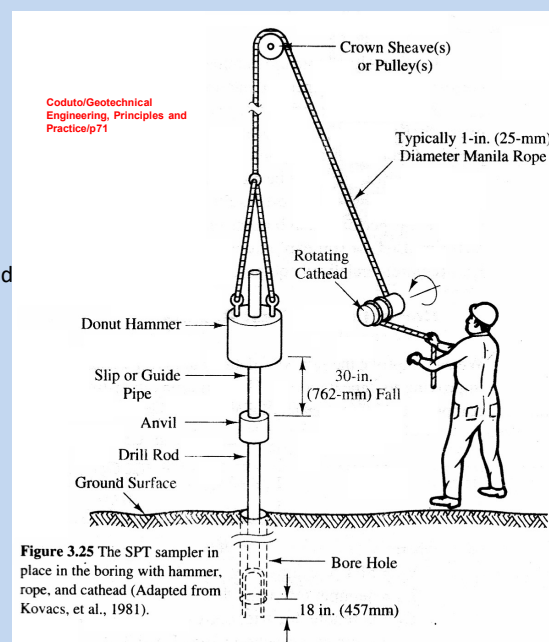
Advantages

Simple equipments
 Low cost
 Do not require much expertise for field operations
 Disturbed samples are collected

Disadvantages

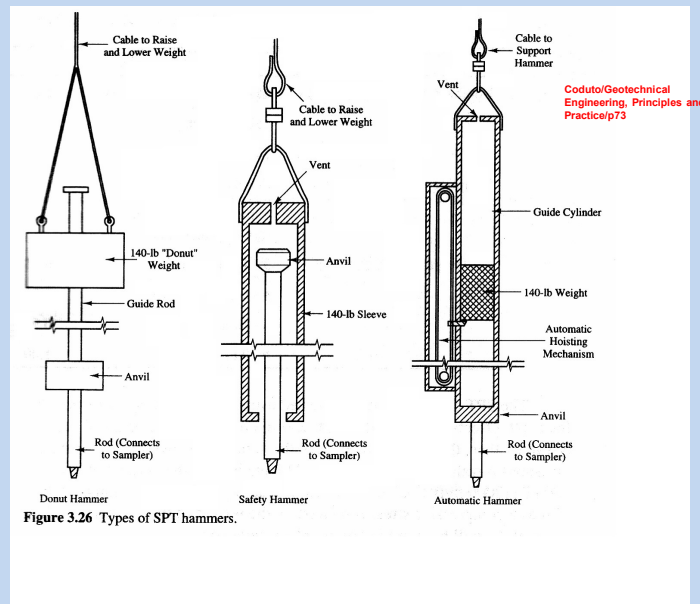
Much variation in the results
 i.e. poor repeatability

L5/P2



2

L5/P3



3

L5/P4

It was regularly observed that N values in adjacent boreholes or from using different equipment in adjacent boreholes were not reproducible.

The variation in N value arises from

Sl.no.1,2,3,4 is associated with energy transmission

1. Equipment from different manufacturers
2. Drive hammer configuration (Donut/Safety hammer/Auto trip)
3. Actual Drop height (variation in manual/auto trip operation)
4. Rope cat-head system : dia and condition (rusty/clean) of rope, no. of turns ($1\frac{1}{2}$, 2, 3 etc.)
5. Use of liner inside the split barrel (usually liner is not used)
6. Overburden pressure – soil of the same density will give smaller N value if p'_o is smaller; oversize borehole (hole dia > 150 mm will reduce the N value)
7. Length and stiffness of drill rod- (if rod length > 10 m – not critical; for shorter lengths and $N < 30$ it is critical)
8. Rate at which blow is applied; sometimes drilling crew are more interested in advancing the hole quickly (30 ~ 40 blow per min. is recommended)
9. Diameter of the drill hole
10. Presence or lack of drilling mud

4

L5/P5

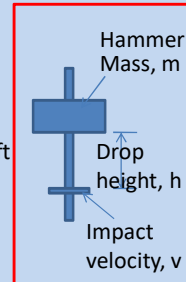
Correction of N value for input energy or hammer efficiency

Some of the influencing factors such as (warped/worn driving shoe, inducing a quick condition in the hole **bottom by too rapid withdrawal of cutter, differential water level between GWT and** in hole etc.) can be avoided. This leaves the **input driving energy and its dissipation around the sampler** into the surrounding soil as the **principal factors** for the wide range of N values.

Theoretical driving energy:
$$E_{in} = \frac{1}{2}mv^2 = \frac{1}{2} \frac{W}{g} (2gh) = Wh$$

Here W=140 lb =63.5 kg, h=30 in = 762 mm, g =9.807 m/s²

Therefore, E_{in} = 63.5 x 9.807 x 0.762 Joule =474.5 J = 350 lb-ft



In reality, actual energy transmitted to the sampler E_a is less.

Energy ratio, $E_m = \frac{E_a}{E_{in}}$ E_m is also termed as Hammer Efficiency

Note: Larger value of E_m decrease the blow count nearly linearly i.e. 'energy ratio (E_m) x blow count (N)' should be a constant. Thus we can convert the N value from one energy ratio to that for another energy ratio using

$$E_{m1} \times N_1 = E_{m2} \times N_2 \Rightarrow N_2 = (E_{m1} / E_{m2}) \times N_1$$

e.g. if N₁ = 15 for E_{m1} = 80, then for E_{m2} =60, N₂ = (80/60) x 15 = 20

5

L5/P6

Energy measurements by different researchers showed wide variation in the actual input diving energy E_a to the sampler to produce penetration

TABLE 3.3 SPT HAMMER EFFICIENCIES (Adapted from Clayton, 1990).

Country	Hammer Type	Hammer Release Mechanism	Hammer Efficiency E _m
Argentina	Donut	Cathead	0.45
Brazil	Pin Weight	Hand Dropped	0.72
China	Automatic	Trip	0.60
	Donut	Hand dropped	0.55
	Donut	Cathead	0.50
Colombia	Donut	Cathead	0.50
Japan	Donut	Tombi trigger	0.78 - 0.85
	Donut	Cathead 2 turns + special release	0.65 - 0.67
UK	Automatic	Trip	0.73
USA	Safety	2 turns on cathead	0.55 - 0.60
	Donut	2 turns on cathead	0.45
Venezuela	Donut	Cathead	0.43

$$E_m = \frac{E_a}{E_{in}}$$

For the system used in Bangladesh, E_m = 0.60

6

L5/P7

SPT Correlations

It is important to know the energy ratio relevant to the SPT-N value used in the correlation .

- SPT ~ Undrained Shear Strength, c_u
- SPT ~ OCR
- SPT ~ Relative Density
- SPT-N value ~ Peak friction angle

Relative comparison of SPT-N value for cohesive and cohesionless soil

Table 5.3 Penetration Resistance and Soil Properties on Basis of the Standard Penetration Test

Peck,Hensen,Thornburn/p.114

Sands (Fairly Reliable)		Clays (Rather Unreliable)	
Number of Blows per ft, N	Relative Density	Number of Blows per ft, N	Consistency
0-4	Very loose	Below 2	Very soft
4-10	Loose	2-4	Soft
10-30	Medium	4-8	Medium
30-50	Dense	8-15	Stiff
Over 50	Very dense	15-30	Very stiff
		Over 30	Hard

7

SPT Correlations for cohesive soils (Not much reliable – used for crude approximation)

SPT ~ Undrained Shear Strength, c_u

Besides obtaining soil samples, standard penetration tests provide several useful correlations. For example, the consistency of clayey soils can often be estimated from the standard penetration number, N , as shown in Table 2.3. However, correlations for clays require tests to verify that the relationships are valid for the clay deposit being examined.

The literature contains many correlations between the standard penetration number and the undrained shear strength of clay, c_u . Based on the results of undrained triaxial tests conducted on insensitive clays, Stroud (1974) suggested that

$$c_u = KN \tag{2.4}$$

where K = constant = 3.5–6.5 kN/m² (0.507–0.942 lb/in²)
 N = standard penetration number obtained from the field

The average value of K is about 4.4 kN/m² (0.638 lb/in²). B.M. Das/Principles of Foundation Engineering/4th edn./p.100

▼ **TABLE 2.3** Consistency of Clays and Approximate Correlation to the Standard Penetration Number, N

Standard penetration number, N	Consistency	Unconfined compression strength, q_u (kN/m ²)
0-2	Very soft	0-25
2-5	Soft	25-50
5-10	Medium stiff	50-100
10-20	Stiff	100-200
20-30	Very stiff	200-400
>30	Hard	>400

Hara et al. (1971) also suggested that

$$c_u \text{ (kN/m}^2\text{)} = 29N^{0.72} \tag{2.5}$$

L5/P10

8

SPT ~ OCR

The overconsolidation ratio, *OCR*, of a natural clay deposit can also be correlated with the standard penetration number. Based on the regression analysis of 110 data points, Mayne and Kemper (1988) obtained the relationship

$$OCR = 0.193 \left(\frac{N}{\sigma'_v} \right)^{0.689} \quad (2.6)$$

where σ'_v = effective vertical stress in MN/m²

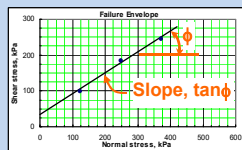
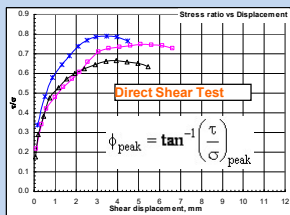
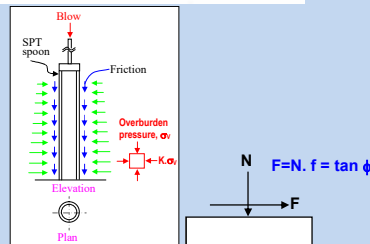
SPT Correlations for Cohesionless Soils Often reliable enough for foundation design)

Correction for Overburden Pressure (Cohesionless soil)

In granular soils, the *N* value is affected by the effective overburden pressure, σ'_v . For that reason, the *N* value obtained from field exploration under different effective overburden pressures should be changed to correspond to a standard value of σ'_v . That is,

$$N_{cor} = C_N N_F \quad (2.7)$$

where N_{cor} = corrected *N* value to a standard value of σ'_v [95.6 kN/m² (1 ton/ft²)]
 C_N = correction factor
 N_F = *N* value obtained from the field



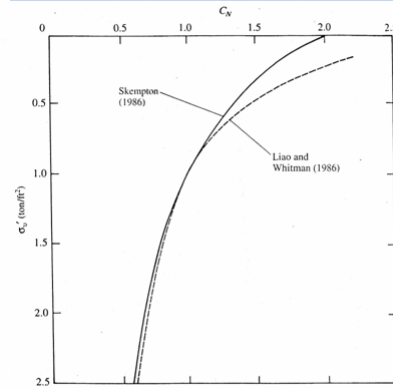
Sand/ Sandy soil (Frictional material) even though the density is same
For greater depth
 -> greater overburden pressure
 -> greater normal pressure on SPT spoon sampler
 -> greater friction
 -> larger *N* value

Cohesionless soil: Correction for Overburden Pressure.....contd.

In the past, a number of empirical relations have been proposed for C_N . Some of the relationships are given in Table 2.4. The most commonly cited relationships are those given by Liao and Whitman (1986) and Skempton (1986). Figure 2.17 plots a comparison of C_N versus σ'_v obtained from those relationships.

▼ TABLE 2.4 Empirical Relationships for C_N (Note: σ'_v is in U.S. ton/ft²)

Source	C_N
Liao and Whitman (1986)	$\sqrt{\frac{1}{\sigma'_v}}$
Skempton (1986)	$\frac{2}{1 + \sigma'_v}$
Seed et al. (1975)	$1 - 1.25 \log\left(\frac{\sigma'_v}{\sigma'_i}\right)$
	where $\sigma'_i = 1$ U.S. ton/ft ²
Peck et al. (1974)	$0.77 \log\left(\frac{20}{\sigma'_v}\right)$
	for $\sigma'_v \geq 0.25$ U.S. ton/ft ²



▼ FIGURE 2.17 Comparison of C_N versus σ'_v plots obtained from the relationships given by Liao and Whitman (1986) and Skempton (1986)

SPT ~ Relative Density

Cohesionless soil.....contd.

An approximate relationship between the corrected standard penetration number and the relative density of sand is given in Table 2.5. However, these values are approximate, primarily because the effective overburden pressure and the stress history of the soil significantly influence the N_F values of sand. An extensive study conducted by Marcuson and Biegansky (1977) produced the empirical relationship

$$D_r(\%) = 11.7 + 0.76(222N_F + 1600 - 53\sigma'_v - 50C_u^2)^{0.5} \quad (2.8)$$

where D_r = relative density
 N_F = standard penetration number in the field
 σ'_v = effective overburden pressure (lb/in²)
 C_u = uniformity coefficient of the sand

▼ TABLE 2.5 Relation between the Corrected N Values and the Relative Density in Sands

Standard penetration number, N_{cor}	Approximate relative density, D_r (%)
0-5	0-5
5-10	5-30
10-30	30-60
30-50	60-95

SPT-N value ~ Peak friction angle

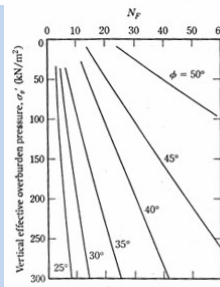
The *peak* angle of friction of granular soils, ϕ , has been correlated to the corrected standard penetration number. Peck, Hanson, and Thornburn (1974) give a correlation between N_{cor} and ϕ in a graphical form, which can be approximated as (Wolff, 1989)

$$\phi \text{ (deg)} = 27.1 + 0.3N_{cor} - 0.00054N_{cor}^2 \tag{2.9}$$

Schmertmann (1975) provided a correlation between N_F , σ'_v , and ϕ , which is shown in Figure 2.18. The correlation can be approximated as (Kulhawy and Mayne, 1990)

$$\phi = \tan^{-1} \left[\frac{N_F}{12.2 + 20.3 \left(\frac{\sigma'_v}{p_a} \right)^{0.34}} \right] \tag{2.10}$$

where N_F = field standard penetration number
 σ'_v = effective overburden pressure
 p_a = atmospheric pressure in the same unit as σ'_v
 ϕ = soil friction angle

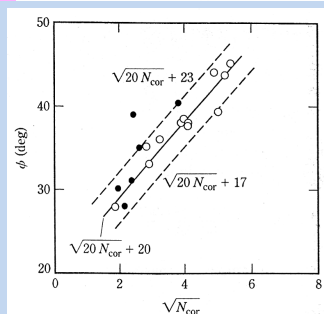


▼ FIGURE 2.18 Schmertmann's (1975) correlation between N_F , σ'_v , and ϕ for granular soils

SPT-N value ~ Peak friction angle.....contd.

More recently, Hatanaka and Uchida (1996) provided a simple correlation between ϕ and N_{cor} (Figure 2.19), which can be expressed as

$$\phi = \sqrt{20N_{cor}} + 20 \tag{2.11}$$



▼ FIGURE 2.19 Laboratory test result of Hatanaka and Uchida (1996) for correlation between ϕ and $\sqrt{N_{cor}}$

L5/P17

Concerns with SPT-N correlations

The results of the standard penetration test can usually be correlated in a general way with the pertinent physical properties of the soil. Table 5.3 shows such a correlation. However, the scattering of individual results from the conservative values given in the table may be quite large, and it is preferable to make direct comparisons with the results of other appropriate tests in any given locality. The correlation for clays can be regarded as no more than a crude approximation, but that for sands is often reliable enough to permit the use of N -values in foundation design.

In saturated, fine or silty, dense or very dense sands, the N -values may be abnormally great because of the tendency of such materials to dilate during shear under undrained conditions (Art. 4.2). Hence, in such soils, the results of standard penetration tests should be interpreted conservatively.

In addition, the value of N in cohesionless soils is influenced to some extent by the depth at which the test is made. Because of the greater confinement caused by increasing overburden pressure, N -values at increasing depths may indicate larger relative densities than actually exist. If the N -value at a depth corresponding to an effective overburden pressure of 1 ton/sq ft is considered to be a standard,

15

L5/P18

By far the most common error in connection with the standard penetration test in sand or silt occurs, however, when drilling is being done below the water table. If the water level in the drill hole is allowed to drop below groundwater level, as may easily occur, for instance, when the drill rods are removed rapidly, an upward hydraulic gradient is created in the sand beneath the drill hole. Consequently, the sand may become quick and its relative density may be greatly reduced. The N -value will accordingly be much lower than that corresponding to the relative density of the undisturbed sand. Care is required to see that the water level in the drill hole is always maintained at or slightly above that corresponding to the piezometric level at the bottom of the hole. For the reasons noted in Art. 5.2, use of the plugged hollow-stem auger as a means for drilling in cohesionless soils below water

table almost inevitably leads to alteration of the relative density; hence, N -values determined under these circumstances should not be relied on.

In deposits containing many boulders the results of standard penetration tests may be unreliable because of the small size of the sampling spoon compared to that of the boulders.

In highly sensitive clays the standard penetration test may lead to a gross misconception of the consistency. Moreover, it is far too crude a test to justify its use for even approximating numerical values representing the strength of soft or very soft saturated clays. The ease of penetration of the sampler depends not only on the strength of the soil but also on its compressibility. Thus a strong cohesive soil with a high air content may have a substantially lower N -value than an equally strong saturated soil in which the voids cannot collapse as the sampler advances.

16

3-9 DESIGN N VALUES

Early recommendations were to use the smallest N value in the boring or an average of all the values. Current practice is to use an average N but in the zone of interest. For example, for a spread footing the zone of interest is from about one-half the footing width B above the estimated base location to a depth of $2B$ below. Weighted averaging using depth increment $\times N$ is usually preferable to an ordinary arithmetic average.

For piles there is merit in averaging the N count for any given stratum unless it is too thick (a relative term), where one or more subdivisions might be used.

The average N'_{70} (or other base value) can then be computed from the average N and stratum data, or individual N'_{70} values can be computed and then averaged.

Prior to about the mid-sixties N values were adjusted⁴ when taken below the water table, however, current practice is not to apply water table corrections. If one is to use N values to obtain the stress-strain modulus E_s , which generally increases with depth, great care is required in adjusting N . For example, using C_N in Eq. (3-3) would modify any N to a value corresponding to a depth producing $\sigma_v = 95.76$ kPa (2 ksf) and eliminate most of any apparent depth effects. On the other hand, if we want a unique value of N for a zone of, say, $2B$ beneath a spread footing we should use C_N with the several N values and average the results.

⁴ Usually as $N' = N + \frac{1}{2}(N - 15)$ for $N > 15$; $N' = N$ for $N < 15$.