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Standard Penetration Test in Engineering Geological Site Investigations – A Review

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ABSTRACT
Prior to the construction of engineering structures, site investigation is required in order to determine the suitability of the site for the intended structure. The results of the investigation furnish information on the engineering properties of earth materials and groundwater conditions of the site.During the field exploration phase, in situ engineering field tests are carried out. These include standard penetration tests (SPT), vane shear tests (VST), cone penetration tests (CPT), flat plate dilatometer tests (DMT) and pressure meter tests (PMT). These tests give results that are used to characterize the strength and deformation properties of earth materials.
The SPT as used in engineering geological site investigation is reviewed in this paper with emphasis on its significance in engineering geological site investigations. The equipment used is the cable percussion drilling rig and its accessories made up of split-spoon sampler, hammer, and drill rods. The SPT is performed by driving the split spoon sampler into the ground by a drop of hammer of mass 64 kg falling from a predetermined height. The hammer blow counts, disturbed and undisturbed soil samples collected during the test are processed and interpreted. The interpreted results are used to estimate the relative density, shear strength of soils and the bearing capacity. Based on these estimates, recommendations for foundation design and construction of civil engineering structures can be made.

KEYWORDS : *Site investigation, Standard Penetration Test, hammer, split spoon sampler*

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I. INTRODUCTION

For safe and economic infrastructural development, it is important that subsoil conditions at any proposed civil engineering site be properly investigated prior to commencement of the final design or construction activities. In other words, there is need to know the characteristics of the formations (rocks and soils) on which the foundation of such structures and ancillary objects are intended to rest or buried. This is for the obvious reason that such engineering structures or objects (e.g. roads, bridges, dam embankments, buildings, etc.) must be anchored on or buried in earth materials of proven integrity. Generally, the overall investigation should be detailed enough to provide sufficient information for the geotechnical engineer to reach conclusions regarding the site suitability, design criteria, probable construction problems and environmental impact (Cernica, 1995). Both laboratory and in situ or field (surface and subsurface) techniques are routinely used to obtain information about engineering properties of rocks and soils. Laboratory techniques include Atterberg limits, pH determination, groundwater quality testing, etc., while geological mapping, geophysical survey, shell and auger boring, core drilling, soil sampling (disturbed and undisturbed), standard penetration tests, pressuremeter tests, permeability tests, water level measurements, test pits are the commonly used field techniques. These techniques are usually deployed in synergy for a given site. The overall consideration in the choice of a method or a combination of methods is the cost implication, although this consideration should not override the need for proper investigation. This paper focuses on the standard penetration test. It is one of the relatively cost-effective and yet informative field techniques most commonly used in subsurface probing.

II. PURPOSE OF ENGINEERING SITE INVESTIGATION

A site investigation program is necessary to provide information for design and construction, and for environmental assessment. Smith (1975) and Budhu (2004) list the following objectives as the most important focus of a site investigation exercise:
i. Assessment of the general suitability of the site for the proposed work.
ii. Foreseeing and provision against difficulties that may arise during construction due to ground and other local conditions.
iii. Acquisition of physical and mechanical properties of soils for adequate and economic design.
iv. Determination of groundwater conditions.
v. Determination of the suitability of materials for construction.

III. PROBLEMS ASSOCIATED WITH INADEQUATE ENGINEERING SITE INVESTIGATION

Any attempt to save costs by having a low budget for an investigation may cause additional expenditure later if unfavorable ground conditions, previously undiscovered, are found during construction stage. In fact, the cost of site investigation is relatively small; it is usually being less than 0.5% of the total cost of the entire work (Budhu, 2004). Economic matter should be regarded as a secondary matter as far as safety is concerned. Project delays, failures and cost over-run are the result of inadequate and inappropriate investigations. Loss of lives and properties could also result from inadequate site investigations. Insufficient or inadequate information with respect to the character of the ground can lead to the production of an unsatisfactory design.

IV. METHODS USED IN SITE INVESTIGATIONS

Site investigation involves both laboratory and in situ techniques. Figure 1 shows the organization of a site investigation.

4.1 *In situ* or field-tests (surface or sub-surface) - This involves exploring the ground at or below the surface.

4.1.1 Surface investigation

a) Geological mapping which will provide information on the general soil profile (e.g., groundwater conditions, flooding, erosion, metastable soil formation), the state of the mass – rock formations (e.g., fractures or faults, formations, voids) and the areas of seismicity.

b) Soil sampling which objective is to obtain soils of satisfactory size with minimum disturbance for observations and laboratory tests. Soil samples are usually obtained by attaching an open-ended thin-walled tube, called a shelby tube or simply, a sampling tube, to drill rods and forcing it down into the soil. The samples can be disturbed or undisturbed. An undisturbed sample can be regarded as one that is removed from its natural condition without disturbing its structure, density, porosity, moisture content and stress condition and can be obtained by hand from surface exposures, pits and trenches. Disturbed samples can be obtained by hand, by auger or from the clay-cutter or shell of a boring rig.

Commonly used *in situ* testing include :- density replacement test which measures the *in situ* density of soil; Penetrometer tests (standard penetration tests and cone penetration tests) which measures the resistance to penetration offered by the soil at any depth thereby providing information on the relative density, shear strength and bearing capacity of the soil ; Shear vane test which measures the undrained shear strength in clays; Load test which provides information by which the bearing capacity and settlement characteristics of a foundation can be assessed; Pressure tests which measures the reaction of a rock mass to stress over large areas, giving values of Young's modulus, elastic recovery, inelastic deformation and creep and in situ shear test provide an estimate of the angle of shearing resistance and cohesion of the rock.

1.1.2 Subsurface exploration

This include geophysical exploration used to determine the geological sequence and structure of subsurface rocks by the measurement of certain physical properties or forces such as density, elasticity, conductivity, magnetic susceptibility and gravitational attraction; test borings or drilling by auger or shell to obtain samples; Core boring for drilling and sampling and test pits to provide information on the stiffness of the strata, the texture and grain size of the soil, moisture evaluation etc.

4.2 Laboratory test – It is essential that laboratory testing of materials be performed as an integral part of the study. The tests carried out will depend on the project being investigated, and the nature of the site. In general, for soils, tests are made to determine grading, index properties, density, compaction, consolidation, and settlement characteristics, strength and permeability (Beavis, 1985). Under some circumstances, special tests may be required, e.g. for dispersion, stabilization, and clay mineralogy and chemistry. For rocks, strength and deformation (elasticity and creep) tests, shear parameters, durability and permeability tests are basic. If the rock is to be used as road aggregate or a concrete aggregate, the rock will need to be tested to determine its suitability for the purpose. All test results obtained in the laboratory require careful analysis by both the geologist and the engineer. If possible, relationships should be established between field and laboratory determined properties.

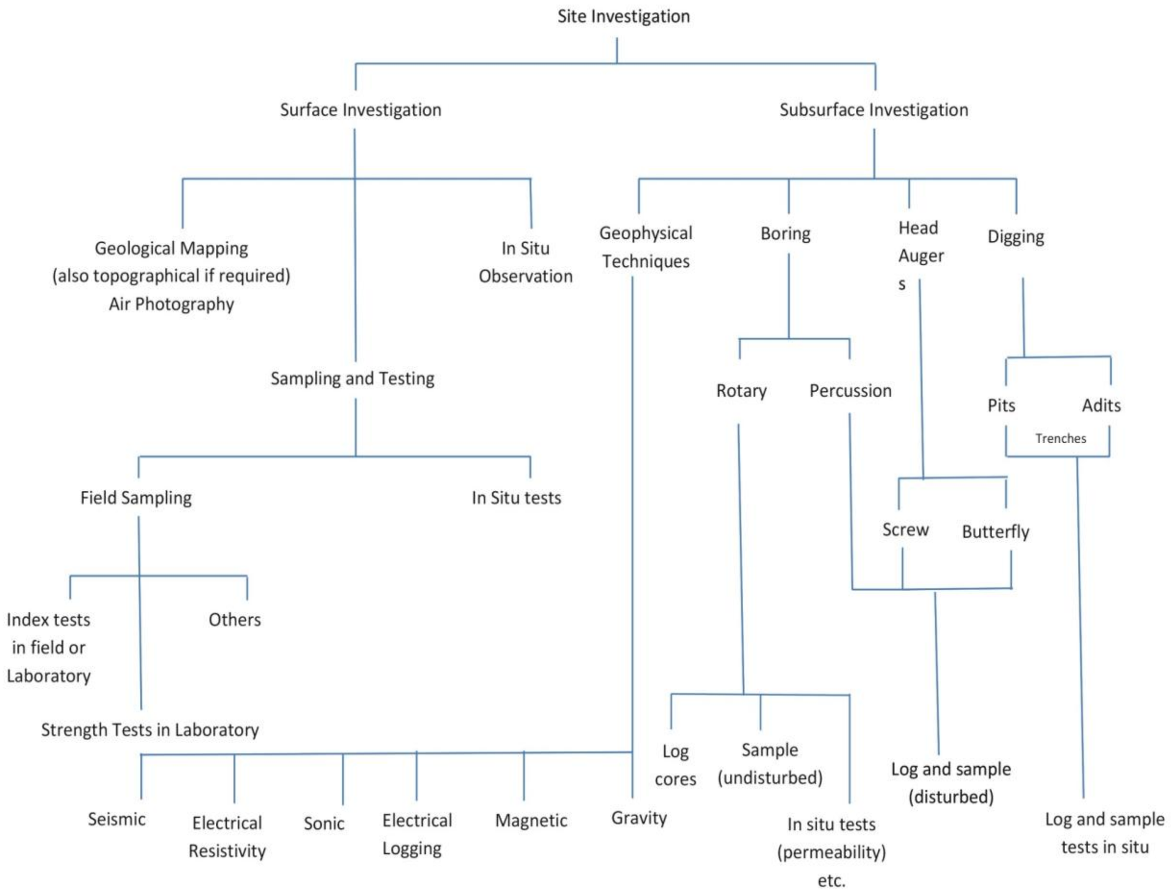

Fig. 1: Organization of a site investigation (source: Bell, 1980)

V. STANDARD PENETRATION TEST IN ENGINEERING SITE INVESTIGATION

The standard penetration test (SPT) was developed circa 1927 and is perhaps the most popular field test. According to Sanglerat (1972), the penetrometer test evolved from the need to acquire data on subsurface soils, which could not be obtained by other means. The penetrometer measures the resistance to penetration offered by the soil at any particular depth. The test was originally designed to determine the relative density of cohesionless soils but its use has been extended to include the design of foundations by determining the load and the required embedment of piles into the bearing strata. The standard penetration test is performed by the use of the cable percussion drilling rig and its accessories.

1.2 The Percussion Drilling Rig

The machine used for making boreholes commonly is called a drilling rig (plate 1). This machine is power driven by gasoline or diesel or compressed air or electric. There is no universal rig, i.e. there is no one type of rig capable of taking every type of sample in every type of subsurface material. The cable percussion rig is used for soil investigation among other uses and is suitable for soil drilling up to a depth of approximately 50 m. It is highly portable and suitable for all terrains. To effect the drilling, some drilling tools are suspended on a cable which is alternately pulled and released to create the up and down motion of the tools. The drill hole is simply sunk by repeated dropping of one of the various tools into the ground. A power winch is used to lift the tool, suspended on a wire, and by releasing the clutch of the winch the tool drops and cuts into the soil. Once a hole is established, it is lined with casing.

Plate 1 A trip hammer attached to a winch cable of the rig

5.1.1 Split-spoon Sampler

The standard sampling tube for obtaining samples from the soil during a standard penetration test is the split spoon sampler. The assembly of the split spoon sampler consists of a short tube with a cutting edge (cutting shoe) on one end and threads on the other (Fig.2). A split tube threads the shoe to a head assembly, which is attached to the drill rod. When unscrewed from the shoe and head assembly, the split spoon sampler can actually be opened into two equal segments for visual inspection of the sample or for removing part of the sample for preservation or future analysis Split spoon samples are generally taken at every change of soil stratum or at specified intervals of depth, usually every 150 mm or at every change of stratum detected by the driller. Such samples are usually regarded as disturbed samples. They are disturbed in the sense that the grain structure of particle arrangement of the soil is altered.

5.1.2 Hammer

Drivage is accomplished by a trip hammer (Plate 1) weighing 64 kg, falling from a distance of 760 mm onto the drive head, which is fitted at the top of the rods (Cernica, 1995). The blow count taken during the hammering provides a rough estimate of (but easily obtainable, very tangible and in many cases sufficiently correct) characterization of the earth material in place (Krynine et al., 2001).

5.1.3 Drill Rods

A rod enclosed in a tube or sleeve (Fig. 2 & 3) is used as a drive rod to help achieve maximum blow on the sampler. It is attached to the drive head from the top and to the sampler at the bottom. The rod is a solid steel rod, rectangular in section, with circular threaded ends to enable as many lengths to be joined together to reach the bottom of the drill hole to be sampled. The rods used for driving the sampler should have sufficient stiffness. Normally, when sampling is carried out to depths greater than around 15m, 54mm rods are used.

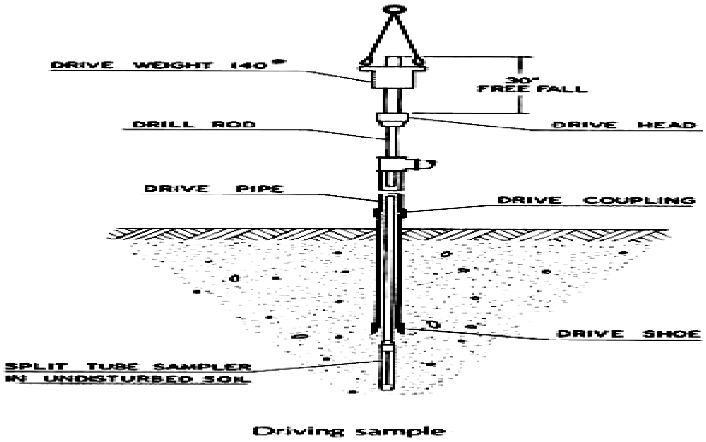

Figure 2: Components of SPT split spoon sampler.
Source:(http://web.mst.edu/~rogersda/umrcourses/ge441/NOTES%20%for%20STANDARD%20PENETRATION%20TEST.pdf.)

1.3 Standard Penetration Test Data Acquisition

The Standard Penetration Test is done to characterize the shear strength of engineering materials by taking note of the number of hammer blows that are required to penetrate a given depth. As the test progresses, soil samples and groundwater information are also collected. A record is made of the number of blows required to drive each 150 mm (6-in) segment into the soil. This is done until 450 mm depth is achieved or otherwise penetration refusal (Fig.4). The blows recorded for the first 150 mm are usually discarded because of fall-in and contamination in the hole. The number of hammer blows required to drive the sampler for the last 300 mm (12-in) is an indication of the relative density of the material and is generally referred to as the *Standard Penetration Number or SPT Blowcount Value (N).* The word “standard” is a misnomer for the Standard Penetration Test, because several methods are used in different parts of the word to release the hammer. Also, different types of anvils and rod lengths are prevalent (Budhu, 2004).

Split-spoon samples (disturbed) of all are generally taken at every change of soil stratum or at specified intervals of depth, usually every 150 mm or at every change of stratum detected by the driller. Data obtained from drilling the boreholes are recorded accurately, completely, and at the time the data become available.

In clays and silts relatively undisturbed samples are taken at depth intervals of 150 mm, this is done by driving thin-walled steel tube into the soil using an Akerman or a U2 hammer to its full length of 45 mm or otherwise penetration refusal. The tube is then pulled to the surface, removed from the sampling hammer, and labeled and waxed top and bottom to prevent natural moisture content from escaping. Groundwater level, where available, is also recorded during the drilling.

As the drilling progresses and information regarding the strata becomes available, either through visual observations of the materials taken from samples taken by the split-spoon or Shelby-tube samplers, the information is immediately recorded. Samples that are saved for future evaluations in the laboratory (Shelby-tube samples or split-spoon samples) are likewise properly labeled on the container in which they are preserved (a jar, a Shelby tube, or a core box). Simultaneously, that information is also recorded in the boring log (Table 1).

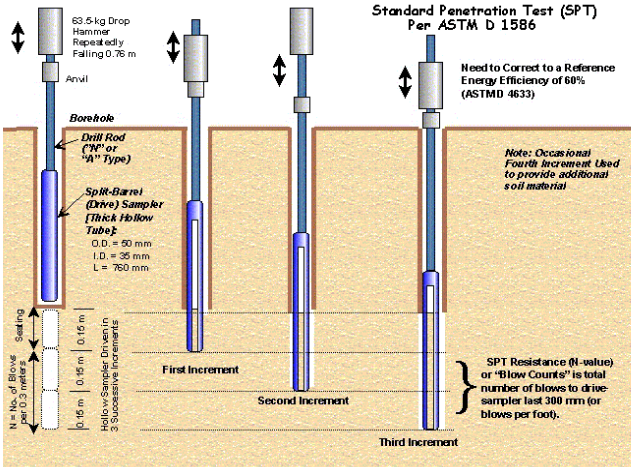

Fig. 3 Driving sequence in an SPT

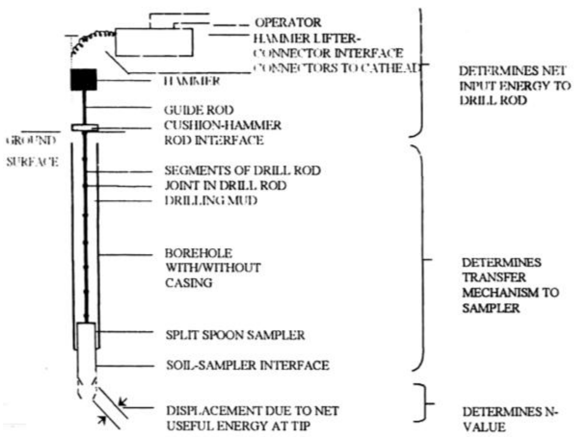

Fig.4: Details of SPT Test (source: Budhu, 2004)

Table 1: SAMPLE DRILL DETAILS – FIELD DATA

From depth	To depth	Lithology		USCS/ 15253	Drilling details								Samples			SPT			Vane Test		Prsureemeter (depth	Box Number	Remarks
					From depth	To Depth	Casing	Typeof Bits(+diameter)		CORE			From depth	To depth	Sample name	Blows 1st	Blows 2nd	Blows 3rd	Undisturbed	Remolded			
(m)	(m)	Soil Type	Description		m	m				TCR	RQD	SR	(m)	(m)					H	D			
0.00	0.20		Silty sand with organic, Fine darkish	MS									Top 0.00	Soil 0.20	WS 1								
													0.20	0.75	WS 2								
0.20	0.75		Silty lean clay with sand										0.75	1.5	WS 3								
0.75	1.5		Sandy lean clay with gravel, reddish moist	CLSL									1.5	1.95	SPT 4	6	8	9					
			==Ditto==										1.95	2.25	WS 5								
1.5	1.95		Silty lean clay with sand and gravel										3.00	3.45	SPT 6	6	6	10					
1.95	2.25		gravel reddish										3.45	3.85	U4	7	50						
				CL				PERCUSSION DRILLING					4.50	4.95	SPT 8	6	7	10					
3.00	3.45		Silty lean clay with sand gravel reddish	CL									6.00	6.45	SPT 9	6	9	15					
													6.45	6.85	U4 10	17	100						
3.45	3.85		==Ditto==	CL																			

The quality of test results depends on several factors, such as energy delivered to the head of the drill rod, the dynamic properties (impedance) of the drill rod, the method of drilling and borehole stabilization. The actually delivered energy can vary between 50 – 80% of the theoretical free fall energy. Therefore, various corrections are applied to the N values to account for energy losses, over burden pressure, rod length, etc. The rod energy ratio is the ratio (in percent) of the energy delivered to the split spoon sampler to the free falling energy of the hammer. It is customary to correct the N values to a rod energy ratio of 60%.This is because some of the energy applied at the top of the rod is dissipated in blows. The corrected N values are denoted as N_{60} and given as:

$$N_{60} = N\left(\frac{ER_r}{60}\right)$$

Typical values for ER_r in North America are 45% for donut hammers and between 55% and 83% for automatic hammers. For the United Kingdom, ER_r = 60% for automatic hammers.

Various correction factors for overburden pressure have been suggested, but only two such suggestions for correcting N values for overburden pressure are included in this text. These are:

$$C_N = \left(\frac{958}{\sigma_z'}\right)^{\frac{1}{2}} : c_N \leq 2$$

(Liao and Whitman, 1986)

$$C_N = 0.77 \log_{10}\left(\frac{1916}{\sigma_z'}\right) \quad c_N \leq 2 \quad > 24k\,Pa$$ (Peck et al., 1974)

where c_N is a correction factor for overburden pressures, is the effective overburden pressure in kPa. A further correction factor is imposed on N values if the ground water level is within a depth B below the base of the footing. The ground water correction factor is:

$$C_W = \frac{1}{2} + \frac{1}{2}\,\frac{z}{(D_f + B)}$$

where z is the depth to the groundwater table, D_f is the footing depth and B is the footing width. If the depth of the groundwater level is beyond B from the footing base, $c_w = 1$. Meyerhof (1965) proposed that no correction should be applied to N values for the effects of ground water as these are already incorporated in the measurement.

The corrected N value is:

$$N_{cor} = C_{rsd}\, C_N C_W \; N\frac{ER_r}{60} \;\; N\,\frac{ER_r}{60}$$

The N value is used to estimate the relative density, angle of shearing resistance and settlement in granular soils. Correction factors for rod length, sampler type and borehole diameter as suggested by Skempton, (1986) are given in Table 2 below.

Table 2: Correction factors for rod length, sampler type and borehole size

Correction Factor	Item	Correction factor
	Rod length (below anvil) ≥ 10 m 6 – 10 m 4 – 6 m 3 – 4 m	 1.00 0.95 0.85 0.70
	Standard sampler **US sampler without liners**	1.00 1.20
	Borehole diameter: 65 -115 mm 150 mm 200 mm	 1.00 1.05 1.15

The depth of penetration is plotted against the number of blows, (N) values obtained from the penetration resistance test. A curve is obtained from the plot after corrections are applied to the N values to account for energy losses, overburden pressure, rod length, etc.

1.4 Standard Penetration Test Data Interpretation

In order to interpret the results of the Standard Penetration Test, a correlation chart is used to determine the mechanical properties of soils and to design foundations. The soil in the split-spoon sampler can be inspected in order to describe the soil profile (Budhu, 2004). From the correlation chart (fig. 5) and the correlation table, the allowable bearing capacity of the soil can be estimated. The number of blows can also be related to the allowable bearing pressure - the coarser or harder the material, the higher the number of blows needed to be able to penetrate the soil in question. Typical correlation among SPT (N blows), relative density (Dr), and angle of internal friction (φ′) are given in Table 3, A and B. Experience and judgment are required to successfully use Tables below:

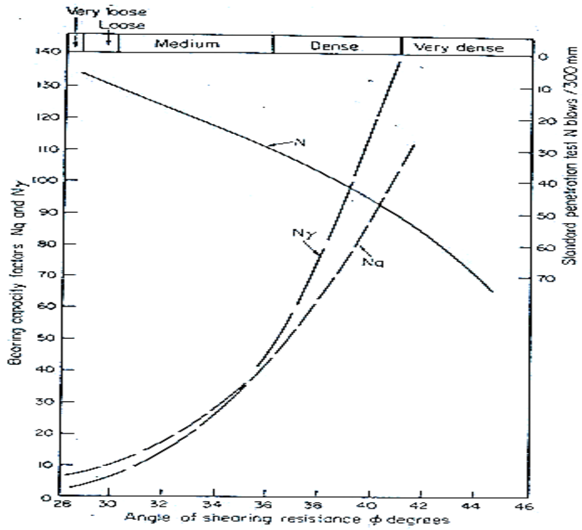

Fig.5. Relationship between the angle of shearing resistance, bearing capacity factors and the N values from the standard penetration test (after Peck, Hanson and Thornburn T.H.Foundation Engineering, Wiley,New York,1974). Soruce : Bell, 1980

Table 3A: Relative density and consistency of soil (after Terzaghi & Peck, 1968 and Sanglerat, 1972).

SPT(N)	Relative Density (D_r)	Description of Compactioness	Static cone Resistance (q_c)	Angle of internal Friction φ′degrees
4	0.2	Very loose	Under 2.0	Under 30
4- 10	0.2 to 0.4	Loose	2.0 to 4.0	30 to 35
10 - 30	0.4 to 0.6	Medium dense	4.0 to 12	35 to 40
30 - 50	0.6 to 0.8	Dense	12 to 20	40 to 45
50	0.8 to 1	Very dense	Over 20	Over 45

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}}$$

e = void ratio

Table 3B : N–values, consistency and unconfined compressive strength of cohesive soils

N	Consistency	Unconfined compressive Strength KN/m^2
Under 2	Very soft	Under 20
2 to 4	Soft	20 to 40
5 to 8	Firm	40 to 75
9 to 15	Stiff	75 to 150
16 to 30	Very stiff	150 to 300
Over 30	Hard	0ver 300

The results obtained from the standard penetration test provide an evaluation of the degree of compaction of cohesionless sands. By correlation from the table, the relative density can be assessed.

SUMMARY AND CONCLUSION

The relationship between all engineering structures and their foundation soils is too important to be flimsy treated or ignored by any nation that aspires to develop. The Standard Penetration Test (SPT), an *in situ* or field technique can provide much of the information required during a site investigation as compared to other field techniques. This is because the method is simple, relatively inexpensive and rugged. The method has the advantage of providing a representative disturbed soil sample in addition to the undisturbed samples obtained during the test. However, the reliability of the method and the accuracy of the result depend largely on the experience and care of the engineer on site. The object of the SPT is to determine the resistance of soil to the penetration of the standard-size sampler, in order to obtain a rough estimate of the properties of soil *in situ*. The test can give valuable information regarding the uniformity and compactness of sand layers. This information together with other information from laboratory tests and other in situ test enables an engineer to reach conclusion regarding the site suitability for any infrastructure, design criteria, construction problems, groundwater conditions, and environmental impact of the structure to be constructed.

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