Standard Penetration Test in Geotechnical Engineering Site Investigations

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Abstract: Site investigation is essential prior to all construction activities of engineering structures for determining the suitability of the site for the construction of the proposed structure. The results from the site investigation gives us the information about the soil profile and the ground water table condition at the site. Various in-situ tests are carried out like Standard Penetration Test (SPT), Electrical Resistivity Technique (ERT), Vane Shear Test (VST), Plate Load Test (PLT), Pile Load Test, Flat Plate Dilatometer Test, Packer Test, Cone Penetration Test (CPT) and many others during the site exploration. The data and results obtained from these tests are essential in identifying the soil type, analyzing and the strength and deformation properties and parameters of soil as well as the ground water condition of the site. This paper intends to summarize the processes and various corrections that are involved in Standard Penetration Test (SPT) and its importance and implication in geotechnical analysis and site exploration. The tools and equipment in this test involved are cable percussion drilling rig, soil sampler (especially split spoon sampler), spirit level, boring machine and a hammer with few other miscellaneous. The soil sampler is pushed or penetrated into the ground by hammer of 63.5kg making it fall freely from a standard height of 750mm. The collected disturbed and undisturbed soil samples, hammer blows and energy are analyzed and interpreted to determine or more specifically to estimate the shear strength of soil, relative density and bearing strength of the soil at different depths. This test also helps in determining the aspects of soil which later can be improved by soil stabilizing or by any one or combination of various ground improvement techniques. In accordance of these interpretations, analysis and estimates, suitable foundation design and further construction work for the proposed structure are recommended.

Keywords: Standard Penetration Test, Split Spoon Sampler, Overburden, Dilatancy, Borelog, SPT-N value

I. Introduction

Geotechnical site investigations are conducted for the purpose of both safety and economy. The soil strata at any site is comprised of various materials like clays, silt, gravels, cobbles, boulders, rocks or combination of any of these materials. Overall investigation of the site and determination of soil properties are required for any Geotechnical engineer to recommend the type of foundation, its suitability and design. Various in-situ and ex-situ (laboratory tests) are conducted to determine the properties of soil and its different parameters. To determine the more accurate values of these soil parameters, tests should be conducted on undisturbed samples rather than on disturbed samples and various corrections are applied on these determined soil parameters. Gradation of soil, Atterberg's limit, Direct shear test, Unconfined Compressive Strength test (UCS), specific gravity and consolidation test are some of the laboratory tests conducted on the soil samples for determining the soil strength and deformation parameters. Groundwater depth, its quality and pH determination are required for studying the water condition at the site. Boring, drilling, SPT, CPT, vane shear test, dilatometer test, ground water table monitoring, geological mapping, trial pits, packer test and permeability tests are some of the field techniques for site exploration. Depending on the site and soil condition and the budget of the proposed project, any of the abovementioned method or combination of these methods are employed. Standard Penetration Test (SPT) is one of the most widely conducted and economic technique of subsurface exploration. Different parameters of the soil can be determined from the results of SPT. Since the SPTs are conducted on the original soil, the values obtained from the SPTs are closer to the values obtained from the undisturbed samples. To determine more accurate results and to make the estimates from the SPT even more accurate, different corrections are applied on the results of the SPTs which are discussed in this paper.

II. Purpose of Geotechnical Site Investigation

C. R. I. Clayton, M. C. Matthews and N. E. Simons (1995) summed up the objectives of geotechnical investigation in the following points:

- To determine the suitability or unsuitability of the site for the proposed structure.
- To determine the suitable foundation type and its design.
- To find out the condition of the currently existing structures by determining the rate of settlement.
- To determine the solution for the problems or any difficulties that may arise during the construction activities and make provisions in accordance to it.
- To determine the solution for the effects and impacts that construction activities have on the environment and the nearby structures.
- To recommend and design the remedial works if any structures are seen to have failed or collapsed or about to fail or collapse.
- To check the safety of the engineering works like earth dams or bridges which are constructed to be in existence and use for a long period of time.

III. Subsurface Exploration

Test drilling, open pits, trenches, boreholes and geophysical techniques are some of the subsurface method of site investigation. Open pits and trenches are comparatively cheaper methods then drillings and borings. Geophysical method includes Ground Penetrating Radar (GPR), Electrical Resistivity Technique (ERT), Seismic Refraction Method and many others. There are various drilling methods like rotary, core, percussion, auger and should be selected on the basis on the type of soil, budget and the type sample to be extracted. Samples are collected by the means of soil samplers. Depending on the mode of operation, soil samplers can be:

- Piston type
- Open Drive
- Scraper bucket
- Rotary type
- Stationary type

Open drive samplers are used to extract the undisturbed samples from cohesive soil whereas piston type is used to extract samples from firm to hard cohesive soils like rocks. On the basis of area ratio samplers can be:

- Thin-wall samplers or
- Thick-wall samplers

The extracted samples are then forwarded to laboratory where they are subjected to various tests to determine various properties like density, grading, consolidation, strength and permeability.

3.1 Standard Penetration Test

As mentioned in "STANDARD PENETRATION TEST (SPT) CORRECTION (M. SHERIF AGGOUR AND W. ROSE RADDING", 2001), historic applications of SPT from ancient times to present can be studied with the help of two literature works. Broms and Flodin (1988) gives the the history of soil penetration testing from the ancient times through the 1980's. Then the University of Florida report (Davidson, Maultsby and Spoor, 1999), discuss the history of SPT testing and the standardization of ASTM for SPT testing from the beginning of the 20th century through the present. Early credits were given to Mohr and Terzaghi for SPT as per the reports.

Previously the test was used just for correlating with the relative density of the soil and now its use has come up to foundation design by load determination. Various studies have been done to correlate the SPT N-value with various parameters of soil. These correlations may not be accurate so various corrections are applied on the field SPT N-value.

A. Percussion Drilling Rig

Drilling rig means the plant and associated support equipment which is used to make a hole or well by boring or other means for geophysical, exploration or production purposes. Drilling rigs are driven mechanically (bit its own engine or diesel) or electrically. Gasoline driven rigs are also used nowadays.

The top drive or Kelly drive of the drilling is connected to the swivel of the pulley through which water or gasoline is passed which ultimately gets through the drilling rod. The drilling is attached to the drilling head. The drilling rod rotates with the driving force and the rod penetrates into the ground and the hole is made. This is the case of rotary drilling. For any other drilling method, one of the various suitable tools is dropped which strikes the drilling head and the drilling rod is thenpenetrated into the ground below:

Figure 1: Drilling rig

Once the hole is made, casing is lined to prevent side fall of the soil on the bottom of the hole which can disturb the test that is to be performed. Rotary drilling is used for drilling holes of greater depths but it has a disadvantage that is the sample extracted will be highly disturbed.

B. Percussion Drilling Rig

Figure 2: Split Spoon Sampler (SPT sample)

The standard split-spoon sampler consists of the following:

- Driving Shoe of 7.5cm long at the bottom
- Steel tube of 45cm long, split into two halves longitudinally.
- A sampler or coupling head about 15 cm long at the top of the tube.

The inside diameter of the steel tube is 3.8cm (1.5 in.) and the outside diameter is 5.08cm (2 in.). The coupling head is provided with a check valve and four venting ports of 1-cm diameter to improve sample recovery. In some split-spoon samplers, a separate sampling tube of 3.8-cm internal diameter is provided. The upper end of the sampler is connected to the end of the drilling rod and with the blows from the hammer it is penetrated into the ground up to the desired depth. The driving shoe helps the sampler to penetrate and the sample is collected in the steel tube.

C. Hammers

The hammers are raised by the means of rope wrapped around the pulley. It is then dropped on the anvil or drilling head sliding through the guide rod.

Different types of hammers used in SPT are:

- Donut hammer
- Safety hammer
- Automatic hammer

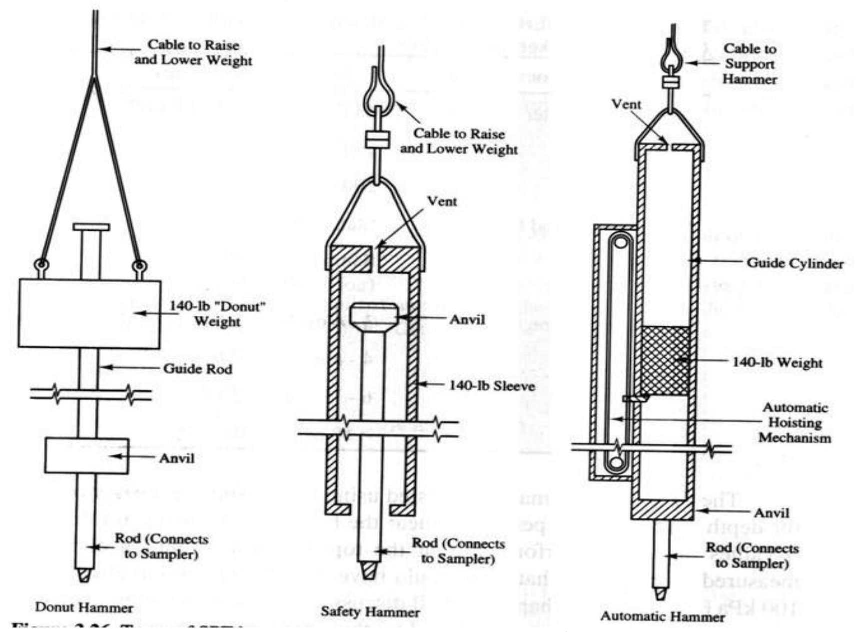

Figure 3: Types of hammers

The safety hammer is comparatively longer and has corresponding smaller diameter. It has an internal striking ram; therefore, the risk of injuries is greatly reduced when using this hammer. The donut hammer is of short length and larger diameter. For transferring energy to the rods through drilling head, safety hammers are more efficient than donut hammers. Therefore, depending upon the hammers used, corrections must be applied.

D. *Drilling Rods*

Drilling rods are provided with suitable threads so that they can be connected to the anvil or drilling head at the top. The lower end of the rod is connected to the sampler. The tube elements are manufactured from cold drawn seamless steel tubing and the end pieces from heat treated alloy steel. They should have sufficient stiffness and rigid threaded joint. Friction welded drill rods increases the life of the drill Rods than the normal drill rods. Drilling rod can be varying length (0.5m, 0.75m, 1m, 1.5m, 2m, 3m and even longer). The rods of connected with each other by threads to achieve the required depth for testing. For conducting the test at more than 15m depth, rods of 54mm diameter are used. Before conducting the test, it must be confirmed that no obstacles like gravel, pebble or layer of any kind is present inside the rod.

3.2 Procedure for Standard Penetration Test

Once the soil sampler has reached the desired depth, the drilling rods just above the ground is marked at every 150mm up to 450mm. Then the hammer is dropped to fall freely which penetrates the soil sampler even below the ground. The marked level on the rod also lowers down. The hammer is dropped repeatedly until the marked 150mm on the rod reaches the ground level. The total number of blows required to penetrate the sample by 150mm is recorded on the bore log sheet. The number of blows required to penetrate every 150mm is recorded on the bore log sheet. The process is continued until the marked 450mm reaches the ground level. The total number of blows required for penetrating the last 300mm mark on the rod is added. This added value of the penetration indicates the relative density of the soil material through the sampler was penetrating and this added number is referred to as Standard Penetration Number, SPT N-value, SPT Blow count Value (N) or simply 'N' value. The word "standard" in Standard Penetration Test is incorrectly applied as the test is conducted following various procedures using different samplers with different kinds of hammers in different parts of the world.

The most widely used sampler during SPT are split spoon samplers. The test is conducted at every interval of 150mm or whenever the soil strata changes. The depth at which the test is conducted and the depth of the ground water table (if encountered) are recorded at each interval of the test in the bore log sheet. In clayey and silty soil, UD tube is penetrated into the soil to extract the sample (Un-Disturbed sample) and penetration is done with the help of U2 hammer. The UD tube filled with undisturbed sample is then extracted out of the soil and to prevent the spreading, falling or pouring of the collected soil sample, plastic is covered or wax is melted on both the ends of the tube. The melted wax when gets cooled, it forms a separate thin layer preventing the falling and pouring of the collected soil sample. As the drilling and the test progresses, the data from each depth interval is recorded on the bore log sheet. Data on the bore log sheet may include color of the collected soil sample, soil type, SPT N-value, relative density, depth of water loss, weathering state (if gravels, cobbles, boulders, or rocks are extracted), depth at which the earth strata is changing. Color and soil type can be characterized by the visual observation. Various relations have been proposed between relative density and SPT N-value. All these data are recorded in a systematic manner in bore log sheet. The collected soil samples are placed in a core box. Core box is generally made of 1m length and the extracted samples are placed in the core box according to depth to know the depth of changes in strata and create a soil profile. The width of the core box should be such that the extracted sample are sufficiently fitted in the box. The number of core boxes depend on the depth of exploration.

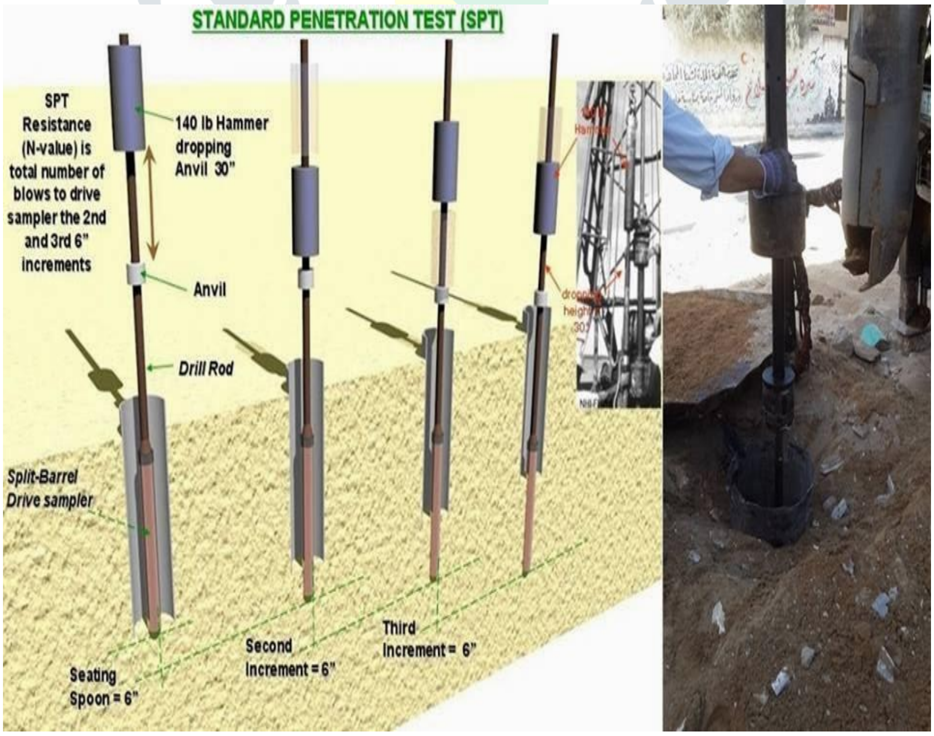

Figure 4: Standard Penetration Test

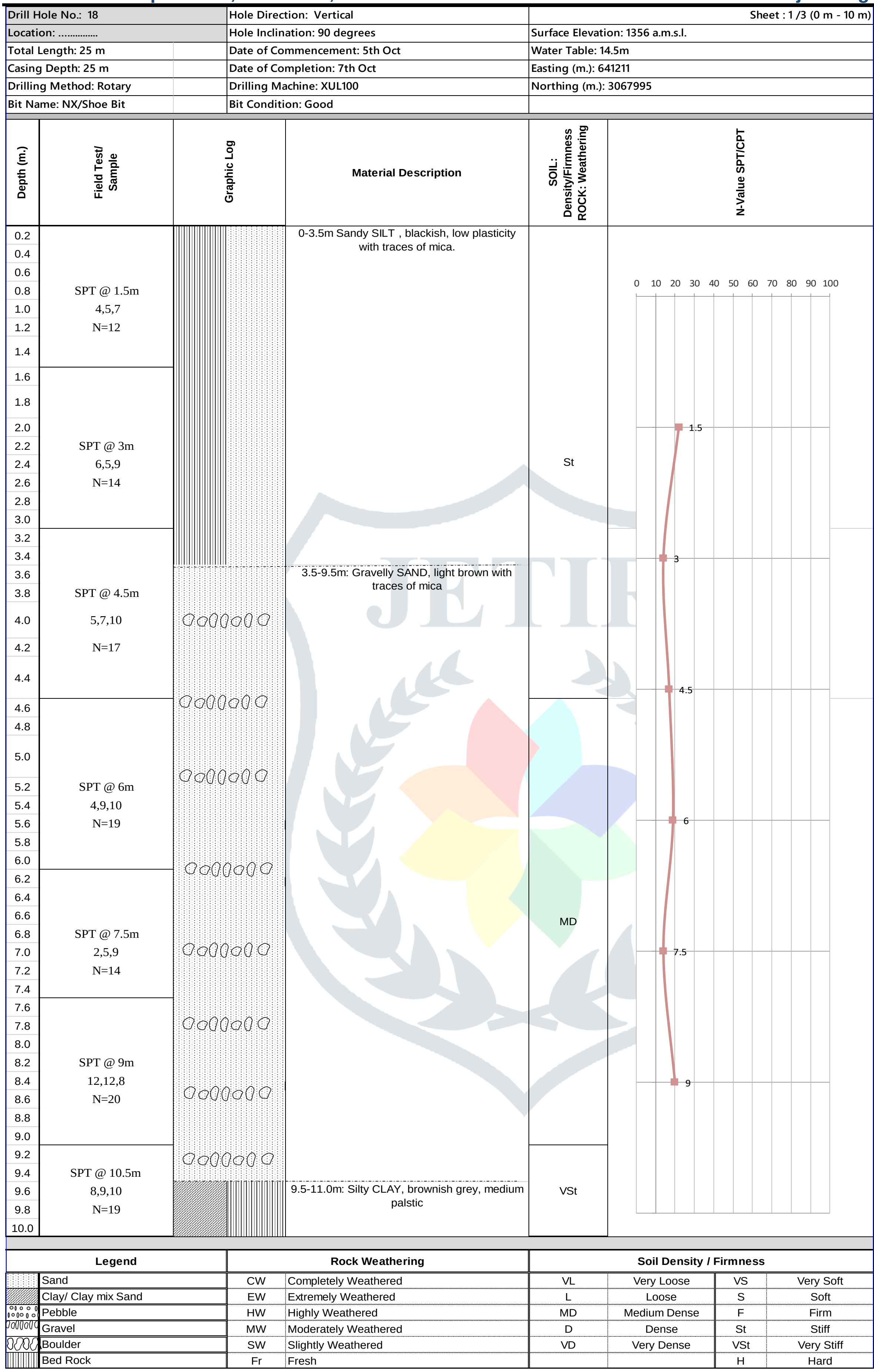

Figure 5: Borehole Log

3.3 Correction Factors

There are various factors that affects the SPT N-value. S. Yimsiri, (2012) discussed how field N-value changes with the type of hammer being used. Three different hammers were used by him: i) safety hammer, ii) donut hammer and iii) trip hammer. He found that the energy ratios for donut hammer, safety hammer and trip hammer were 49%, 68%, and 95% respectively.

The standardization compensates for the variance in the efficiencies of different SPT hammer types, and improves the accuracy and reliability of soil strength estimates that are used in geotechnical applications.

N_{60} for a safety hammer (cathead and rope), N value is estimated to be uncorrected. The efficiency of auto hammer is estimated to be about 80% which is 1.333 times more than a safety hammer. The field N-value is required to be corrected to a normalized 60% standard energy ratio with addition to a number of other corrections and is usually expressed by the following form as proposed by Skempton, (1986).

$$N_{60} = \left(\frac{ETR}{60}\right) x\, N\, x\, C_b * C_s * C_r$$

Where, N = SPT-N value recorded in field
ETR = Average energy ratio determined in the field
C_b = Correction for Borehole diameter
C_s = Correction for Sampling method
C_r = Correction for rod length

A. *Overburden Correction*

The N_{60} is then corrected for overburden pressure which is expressed in in the following form:

$$N_{60} = N_{rec} * C_N$$

where, C_N = Overburden correction factor

The expression proposed by Liao and Whitman (1986) for overburden correction factor is:

C_N= (pa/σ'v)0.5
where, p_a is reference pressure = 100kPa and σ'_v is vertical effective pressure at the SPT test point.
Various other expressions for correction factor are found in literatures. Overburden Correction factor as suggested by Gibbs and Holtz is:

$$N_c = C_N * N'_c = \frac{4N'_c}{0.01P'_o + 0.8}$$

where, N'_c is the original SPT- N value, C_n is the correction factor, p'_o is the overburden pressure at the SPT test point and N_c is the corrected SPT-N value.
In no case the corrected values shall be greater than twice the observed values.
The correction suggested by Bazara is:

$$N_c = C_N * N'_c = \frac{4N'_c}{0.01P'_o + 0.8}$$

for $P'_o \leq 75\ kN/m^2$

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In this case also the corrected values shall not be greater than twice the observed values.

B. *Dilatancy Correction (For fine sand and silts below water table)*

When the water table is at the depth at which the SPT test is conducted and contains sand and silt, the SPT-N value is to be corrected for dilatancy. If the N-value is less than 15, the N-value need not need to be corrected for dilatancy. Terzaghi and Peak (1976) give correction for water pressure.

If, $N_{rec} \leq 15, N_{rec} = N_{corr}$

If, $N_{rec} \geq 15, N_{corr} = 15 + 1/(N_{rec} - 15)$ Then for bearing capacity analysis N_{corr} is used as the N in the

correlation provided by different researchers. The correction factors by different authors are tabulated below:

Table. 1. Correction Factors as proposed by Seed (1984) per McGregor and Duncan (1998)

Factor	Variable	Correction
Energy Ratio	Automatic or Trip Hammer	1.67
	Pulley Safety or Rope Hammer	1.00
	Donut Hammer	0.75
Rod Length	>10 m	1.00
	6-10 m	1.00
	4-6 m	1.00

	3-4	1.00
	0-3	0.75

Table. 2.CORRECTION FACTORS AS PROPOSED BY SKEMPTON (1986)

Factor	Variable	Correction
Energy Ratio	Automatic or Trip Hammer	Not listed
	Pulley Safety or Rope Hammer	0.90
	Donut Hammer	0.75
Rod Length	>10 m	1.00
	6-10 m	0.95
	4-6 m	0.85
	3-4 m	0.75
Sampler	Without liner	1.20
	With liner: dense sand, clay	1.00
	With liner: loose sand	1.00
Borehole Diameter	6-12 cm	1.00
	15 cm	1.05
	200 cm	1.15
Anvil Size	Small	0.6-0.7
	Large	0.7-0.8

Table. 3 CORRECTION FACTORS AS PROPOSED BY ROBERTSON WIDE (1997)

Factor	Variable	Correction
Energy Ratio	Automatic or Trip Hammer	0.8-1.5
	Pulley Safety or Rope Hammer	0.7-1.2
	Donut Hammer	0.5-1.0
Rod Length	>30 m	<1
	10-30	1.00
	6-10	0.95
	4-6	0.85
	3-4	0.75
Sampler	Without liner	1.1-1.3
	With liner: dense sand, clay	1.00
	With liner: loose sand	1.00
Borehole Diameter	6-12 cm	1.00
	15 cm	1.05
	200 cm	1.15

Table.i4iCORRECTION FACTORS AS PROPOSED BY BOWLES (1996)

Factor	Variable	Correction
Energy Ratio	Automatic or Trip Hammer	1.14-1.42*
	Pulley Safety or Rope Hammer	1-1.14*
	Pulley Donut and Rope Hammer	0.64*
Rod Length	>10 m	1.00
	6-10 m	0.95
	4-6 m	0.85
	0-4	0.75
Sampler	Without liner	1.00
	With liner: dense sand, clay	0.80
	With liner: loose sand	0.90
Borehole Diameter	6-12 cm	1.00

Factor	Variable	Correction
	15 cm	1.05
	200 cm	1.15

C. Interpreting N-value and its correlation with different soil properties

SPT-N value can be correlated to various soil properties like relative density, cohesion, degree of compactness, angle of friction and undrained shear strength. Various studies on empirical relationships for different soil types have been done in the past. Empirical relations were developed between cohesion and SPT N value, and between angle of friction and SPT N value (Brown and Hettiarachchi 2008; Hettiarachchi and Brown 2009). Suzuki et al. (1993) and Hatanaka and Uchida (1996) established empirical correlations between SPT N-value and angle of friction. Hara et al. (1974); Sivrikaya and Togrol (2006) and Kalantary et al. (2009) developed correlations between SPT-N value and undrained shear strength. Many correlations were developed between SPT-N value and shear wave velocity by Hara et al. (1974), Wei et al. (1996), Miura et al. (2003), Hasancebi and Ulusay (2007), Anbazhagan and Sitharam (2010), Maheshwari et al. (2010), Akin et al. (2011), Anbazhagan et al. (2012, 2013), Sun et al. (2013), Chatterjee and Choudhary (2013) and Rao (2013).

Table.5 RELATIVE DENSITY, COMPACTNESS AND ANGLE OF FRICTION WITH SPT-N VALUE (AFTER TERZAGHI & PECK, 1968 AND SANGLERAT, 1971)

SPT-N value	Relative Density	Description of Compactness	Static cone resistance	Angle of friction
<4	0.2	Very loose	<2.0	<30°
4 to 10	0.2 to 0.4	Loose	2.0 to 4.0	30° to 35°
10 to 30	0.4 to 0.6	Medium dense	4.0 to 12	35° to 40°
30to 50	0.6 to 0.8	Dense	12 to 20	40° to 45°
>50	0.8 to 1	Very Dense	>20	>45°

Table.6 CONSISTENCY AND UNCONFINED COMPRESSIVE STRENGTH WITH SPT-N VALUE (AFTER TERZAGHI & PECK, 1968 AND SANGLERAT, 1971)

SPT-N value	Consistency	Unconfined compressive strength, kN/m2
<2	Very soft	<20
2 to 5	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
>30	Hard	>300

Table.7 CORRELATION BETWEEN SHEAR WAVE VELOCITY AND SPT-N VALUE

SPT-N value	Soil Type	Shear wave velocity, Vs, m/s	Poisson's ratio, v
0-20	Loose granular soil	130-280	0.2-0.4
20-50	Dense granular soil	200-410	0.3-0.45
0-6	Soft clay	40-90	0.15-0.25
6-30	Stiff clay	65-140	0.2-0.5

With the interpretations and correlations, various other soil parameters can be calculated which are required for designing the foundation of the structure.

Conclusion

SPT is one of the most effective and economic technique used for the geotechnical site investigation. The main objective of conducting SPT is determining the N-value which is actually the resistance offered by the soil to the sampler penetrating inside it. Along with the N-value, SPT also provides us with SPT sample (Undisturbed sample) which can be tested in laboratory to determine various properties of soil. The application of SPT is not limited to only detrmining N-value because the N-value can be correlated with various other properties of soil which helpls in better understanding of the soilat the site. These correaltions and the field N-value are useful for determinig soil parameters but we should know that there are some errors in the tests and the emperical equations that gives the correlation. Theses errors can give false understanding about the site. Theresore it is necessary to follow the standard codes like IS code, ASTM code or BS code as per the project requirement while perforimg the test. With addition to it, various corrections are also applied to for reliability.

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