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Standard Penetration Test (SPT) Pitfalls and Improvements

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Abstract. Standard Penetration Test (SPT) is one of the in-situ tests conducted for onshore and near shore soil investigation projects. SPT test data are extensively used for estimation of soil design parameters needed for geotechnical analysis. However, quality and reliability of SPT results are, very often, not satisfactory due to various reasons such as variable height of fall of hammer, inclination of driving rods, improper release of hammer resulting in partial energy transfer, etc. A study is carried out to determine SPT hammer efficiency for different hammer operating systems being used in India. SPT hammer energy measurements were carried out at three project sites using different SPT hammer operating system. This paper summarizes ways to improve quality of SPT test results and presents the results of energy measurements made using "SPT Analyser".

Keywords: SPT, SPT Analyzer, SPT corrections, Energy measurement.

1 Introduction

Standard Penetration Test (SPT) is one of the in-situ tests conducted for onshore and near shore soil investigation projects. Correlations based on SPT N values are extensively used for the estimation of design soil parameters. In addition, the settlement calculation and liquefaction analysis of cohesionless soils are based on the SPT N values.

Review of current practices in India show many drawbacks/ pitfalls in the measurement of SPT N values, which leads to errors in the measured SPT N values. A study is carried out to understand the effect of various SPT hammer operating systems. This paper presents the results of three case studies and summarizes the ways to improve quality and reliability of SPT test results.

2 Background

In early 1900, geotechnical soundings were used just for delineating soil and rock interface using cuttings from wash boring (David Rogers, 2009). Around 1902, Colonel Charles R Gow (Hvorslev, 1949), started using 1-inch diameter drive sampler. Later, Harry Mohr (Mohr, 1940) developed 2-inch split-spoon sampler and standardized the testing procedure.

Terzaghi (1947) liked Harry Mohr's split spoon sampler and named it as "Standard Penetration Test". Terzaghi and Peck (1948) presented first published SPT correlations. The 2-inch diameter split spoon sampler became a nationwide standard in USA in 1958 and the apparatus and procedure were officially adopted by ASTM as test method D1586.

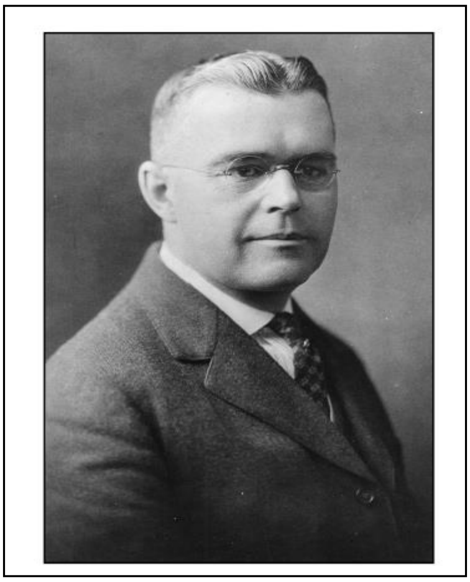

Fig. 1. Colonel Charles R. Gow (1872-1949 **)**

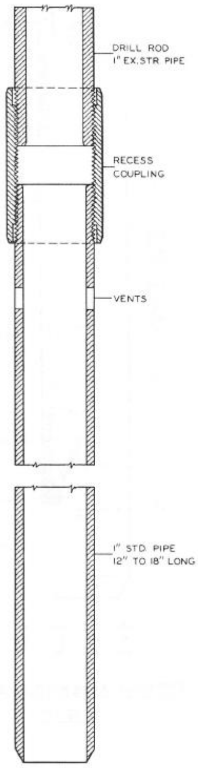

Fig. 2. Gow's Pipe Sampler

As per Indian practice, IS 2131-1981 provides guidelines for conducting SPT and corrections to be applied to the measured SPT N values. This code gives corrections for only overburden and dilatancy of soils.
IS 1893 (Part 1)-2016 provides guidelines for correction factors for non-standard SPT equipment and procedures and a summary is given below.

$$N_{60} = N \times C_{60} \quad (1)$$

where, N = measured (uncorrected) SPT blow count
N_{60} = normalized SPT blow count

$C_{60} = C_{HT} \times C_{HW} \times C_{SS} \times C_{RL} \times C_{BD}$
C_{HT} = correction factor for non-standard hammer weight
= 0.75; for Donut hammer with rope and pulley
= 1.33 for Donut hammers with trip/auto release mechanism
C_{HW} = correction factor for non-standard hammer height of fall
= (H * W)/48387; H = height of fall in mm; W = hammer weight in kg.
C_{SS} = correction factor for non-standard sampler
= 1.1; sampler with room for liners, but used without liners (loose sand)
= 1.2; sampler with room for liners, but used without liners (dense sand)
= 0.9; sampler with room for liners, liners used (loose sand)
= 0.8; sampler with room for liners, liners used (dense sand)
C_{RL} = correction factor for rod length
= 0.75; for rod length 0 to 3 m
= 0.80; for rod length 3 to 4 m
= 0.85; for rod length 4 to 6 m
= 0.95; for rod length 6 to 10 m
= 1.00; for rod length 10 to 30 m
C_{BD} = correction factor for non-standard borehole diameter
= 1.00; for borehole diameter of 65-115 mm
= 1.05; for borehole diameter of 150 mm
= 1.15; for borehole diameter of 200 mm

For cohesionless soils, correction for overburden is applied as below.

$$(N_1)_{60} = C_N \times N_{60} \quad (2)$$

where C_N = correction factor for overburden pressure

$$= 0.77 \times \log(2000/\sigma') \quad (3)$$

where, σ' = effective overburden pressure at the time of testing, in kN/m^2

For fine sand and silt below water table (IS 2131-1981), dilatancy correction is applied for SPT N values corrected for overburden pressure, which is greater than 15, as below.

$$(N_1)''_{60} = 15 + ½ * [(N_1)_{60} - 15] \quad (4)$$

3 Geotechnical Design and Importance of SPT N value

SPT N values are extensively used in geotechnical design, using correlations developed by Terzaghi and Peck (1967) and by others to arrive at different in-situ soil parameters. Also SPT N values are used for estimating bearing capacity and settlement of foundations.

3.1 In-situ properties of soils

SPT N values are is used to estimate various soil parameters such as, unit weight, relative density, angle of internal friction of cohesionless soils, unconfined compressive strength of cohesive soils, and stress-strain modulus of soils.

3.2 Allowable bearing capacity of foundations

Allowable bearing capacity, for cohesionless soils, is given by Terzaghi and Peck (1948), using SPT N value originally in graphical forms. Later many engineers, Meyerhof (1956), Skempton (1951), Teng (1962), Parry (1977), and Bowles (1997) proposed their equations using SPT N value to estimate allowable bearing capacity of foundations, which are available in published literature.

3.3 Pile design

IS 2911 (Part 1/Sec 2): 2010, Annex B-4 includes a method of using standard penetration test N value for arriving at ultimate pile capacity for a bored cast-in-situ piles.

3.4 Liquefaction analysis

Liquefaction resistance of soil is determined using SPT N value, $(N_1)_{60.}$ IS 1893 (Part 1): 2016, Annex-F presents simplified procedure for evaluation of liquefaction potential using SPT N values.

4 Pitfalls in SPT Measurements

SPT N values play a major role in the estimation of soil parameters, bearing capacity of foundations and liquefaction analysis. However, in practice, the equipment used and operational procedures considerably influence measured SPT N values. Following are some of the common pitfalls in the SPT measurements.

1. Using non-standard hammer weight (Standard weight of hammer is 63.5 kg).
2. Using variable drop heights of hammer due to manual operations (Standard drop height of hammer is 760 mm).
3. Restricted free fall of the hammer. Using more than 2 turns of rope around the drum and / or using wire cable restrict the free fall of the hammer weight. (Usually 1-1/2 to 2 wraps of rope around the drum help free fall of hammer).
4. Inclination of driving rods. Hammer weight not striking the drive cap (anvil) concentrically, resulting in increased SPT N values.
5. Not using a guide rod for hammer, resulting in incorrect SPT N values.
6. Incorrect drilling and sampling procedures.
   a) Drilling non-standard diameter boreholes. Larger diameter may result in decrease in blow count. (About 100-130 mm diameter borehole is a standard recommended practice).
   b) Inadequate cleaning of boreholes.

c) Failure to maintain sufficient hydrostatic head in borehole. The water level in the borehole must be at-least equal to the piezometric level especially in sandy strata. If not, soil at the bottom of the borehole may get disturbed to a loose state.
d) Over washing the borehole ahead of casing, resulting in low blow count.
e) Not seating sampler spoon on undisturbed soil, resulting in incorrect SPT N value.
f) Over driving the sampler, resulting in higher blow count.

7. Inadequate supervision. Accurate recording of drilling, sampling and depth shall be done by an experienced supervisor / Engineer. Sometimes, higher blow counts may be observed when gravel piece plugs (the layer is not gravel) sampler which may not be recognized by an inexperienced observer.

5 Improvements in SPT

Following are some of the measures taken, in order to minimize the errors in the measurements of SPT N value.

1. Using Donut hammer with standard weight or measuring the weight of hammer to apply relevant correction.
2. Using Auto-trip hammer system. This ensures standard drop height and free fall of the hammer for all blows, and eliminates the errors due to variable drop height and restricted free fall of hammer.
3. Using "SPT Analyser" for the measurements of energy transferred to driving rods.
4. Maintaining the verticality of drill rods. This needs further improvements considering the safety of operations.
5. Ensuring adequate supervision by an experienced Engineer at project site.

6 Case Studies

A study is conducted to understand the effectiveness of different SPT hammer operating system being used in India. The "donut hammer" with the following different operating system is studied at different project sites; Site-A, Site-B, and Site-C. SPT analyzer is used to measure energy transferred to driving rods in all the project sites. Three cases of hammer operation systems were considered.

Case-1: Donut hammer – manual operation using manila rope
Case-2: Donut hammer – winch operation using steel wire rope
Case-3: Donut hammer – Auto trip hammer, operated by winch

6.1 SPT Analyzer

SPT analyzer measures energy transferred by SPT hammers using force and velocity measurements. It provides a means to measure transferred energy into drill string while performing a standard penetration test (SPT).
The force and velocity measurement are obtained from sensors comprising, two strain gauge bridges and two accelerometers, instrumented on to a SPT rod which is, in turn, is connected at the top of drill string, below the hammer anvil during SPT test.
SPT analyzer obtains, processes force and velocity time histories and display the normalized force units along with various other pertinent parameters such as transferred energy and driving system efficiency in real time during the test.

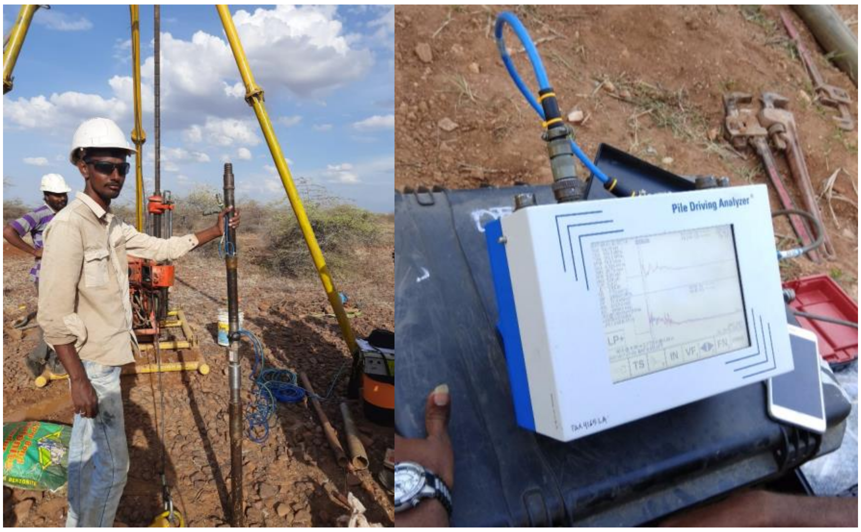

Fig. 3. a) Instrumented Rod b) Pile Driving Analyser for Energy Measurement

6.2 Site-A

Site-A is for solar power plant project in Karnataka, India. Calyx Rotary drilling rig was used for drilling operations. Donut hammer was used and operated manually using manila rope (Case-1). The SPT hammer energy was measured using SPT analyzer, and the energy transferred to each blow was recorded.

6.3 Site-B

Site-B is for construction of Coal Jetty for thermal power project in Tamilnadu, India. Offshore soil investigation was conducted using jack up barge and Calyx Rotary drilling rig placed over the jack up barge. Donut hammer was used and operated by winch using steel wire rope (Case-2). The SPT hammer energy was measured using SPT analyzer, and the energy transferred to each blow was recorded.

6.4 Site-C

Site-C is for high grade steel plant in Andhra Pradesh, India. Soil investigation was done using Hydraulic Rig. Auto-trip hammer (Donut hammer with auto trip mechanism) was used for SPT tests (Case-3). The hammer was operated by winch using steel wire rope. The SPT hammer energy transferred was measured using SPT analyzer.

Fig.4. SPT Energy measurements at Site-A.

Fig.5. SPT Energy measurements at Site-B

Fig.6. SPT Energy measurements at Site-C

7 Results and Discussions

The results of SPT energy measurements for Site-A, Site-B, and Site-C are presented in Figs 7, 8, and 9 respectively.

Site-A: Measured hammer energy (Fig.7) varies from 30 to 75 %, with an average energy ratio of 55 %. The measured transmitted energy indicates high fluctuations of energy between hammer blows. The variations in energy are mainly due to manual operations. However, the average energy is about 55 %, which is close to the standard energy level of 60 %.

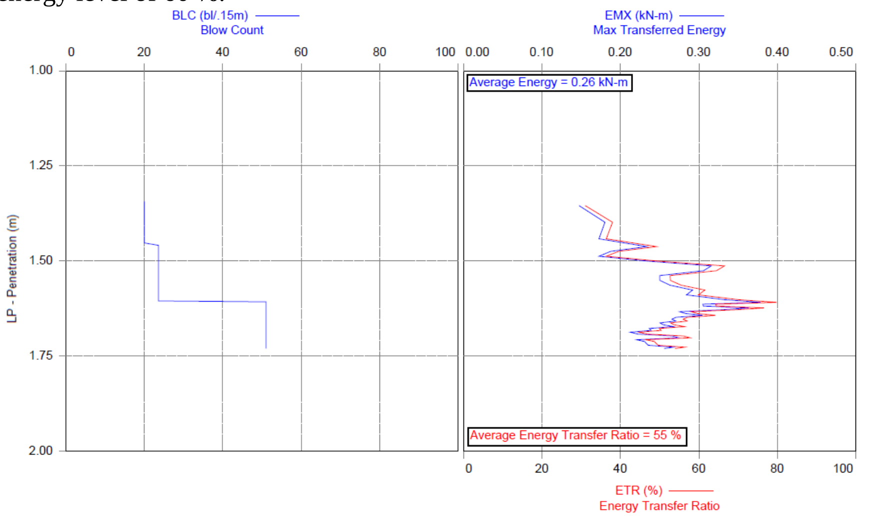

Fig.7. Results of SPT Energy measurements at Site-A

Site-B: Measured hammer energy (Fig.8) varies from about 35 to 42 %, with an average energy ratio of 39 %. The fluctuations of energy between hammer blows are low compared to Site-A. However, the measured energy level is low compared to the standard energy level of 60 %. The low energy measured is mainly due to inclination of SPT rods and winch operation which limits free fall of SPT hammer.

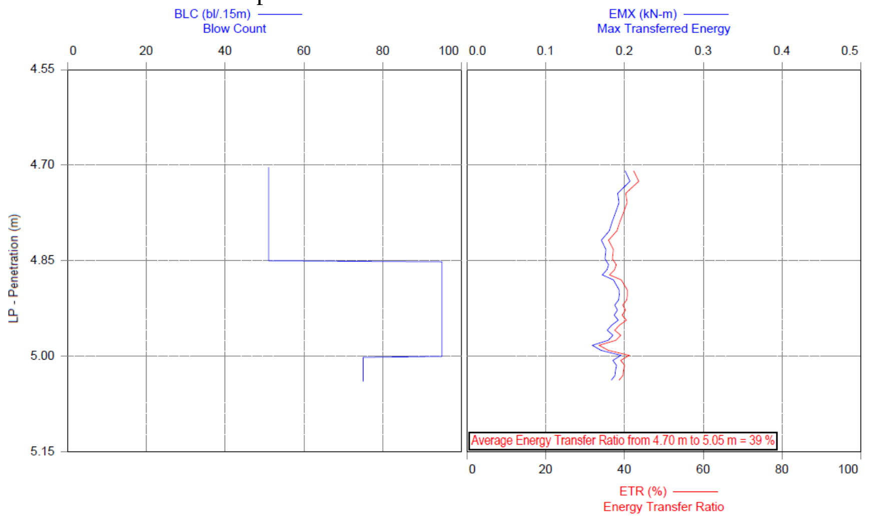

Fig.8 Results of SPT Energy measurements at Site-B

Site-C: Measured hammer energy (refer Fig.9) varies from 65 to 90 %, with an average energy ratio of 77 %. The measured energy is higher than the standard energy level of 60 %. The higher measured energy is mainly due to the usage of auto-trip hammer system, which ensures standard drop height and free fall of hammer for all blows. The variation of energy between blows is due to inclination of driving rod during SPT test. We also observed that improper connection (loose) between driving rods results in lower energy transfer.

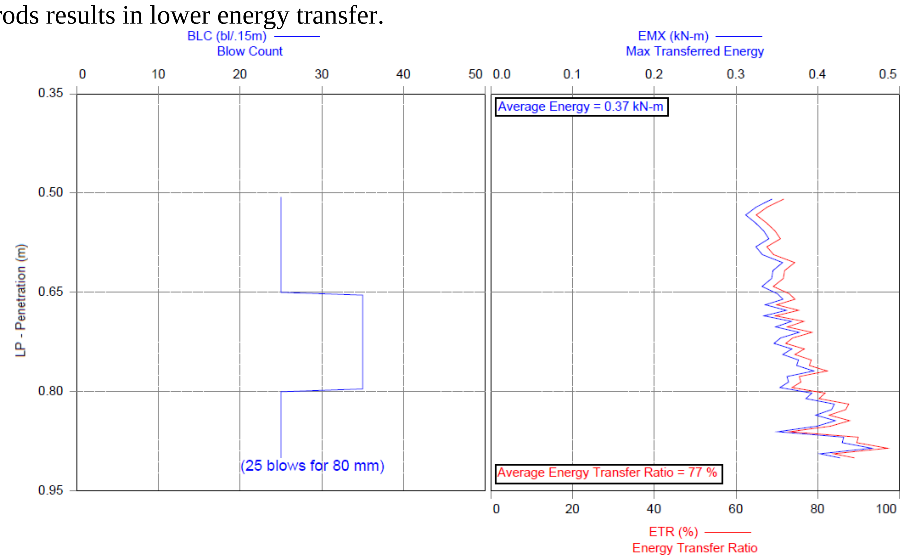

Fig.9. Results of SPT Energy measurements at Site-C

8 Conclusions

1. SPT hammer operating system influences energy delivered to driving rods. Donut hammer system operated manually using manila rope delivers energy with high fluctuations between blows. There is no consistency in energy transfer and depends on operators.
2. Donut hammer operated by winch using steel wire delivers almost consistent energy transfer. However, the energy transfer ratio is low as compared to the standard energy level of 60 %.
3. Auto-trip hammer system (Donut hammer) delivers SPT hammer energy higher than the standard energy level of 60 %.
4. The measurement of SPT hammer energy (using SPT Analyser) helps to normalize the SPT N value to N_{60} which is used for geotechnical design. In-spite of variations in energy delivered by different SPT hammer operating system, energy measurement helps to normalize measured SPT N value to standard value of N_{60}.

5. The inclination of SPT driving rods results in lower energy transfer as compared to vertically maintained driving rods. Maintaining the verticality of SPT rods during testing needs improvement.

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