Proceedings of the 8th World Congress on Civil, Structural, and Environmental Engineering (CSEE'23)
Lisbon, Portugal – March 29 – 31, 2023
Paper No. ICGRE 160
DOI: 10.11159/icgre23.160

Influence of Hammer Energy Correction on SPT Correlations and Interpretation

Ayush Kumar[1], Anbazhagan Panjamani[1], Yadhunandan ME[1]
[1] Indian Institute of Science
CV Raman Avenue, Bengaluru, Karnataka, India, PIN 560012
First.ayushkumar@iisc.ac.in; Second.anbazhagan@iisc.ac.in

Abstract - Standard Penetration Test (SPT) is a widely used geotechnical exploration test. SPT is easy to perform and is cost-effective; hence it has become prevalent. Several factors affect the test results, i.e., the number of blows (N-value) for penetration of the sampler into the soil at any given depth. Among those factors, hammer energy (E_H) is the most important. Even though it is essential, there have been limited studies considering the influence of E_H on the determination of different subsurface properties correlated with N-values. Several empirical relations have been developed between N-value and static and dynamic subsurface properties which however, can be used only to a particular region and a specific E_H value. The influence of considering proper in-situ hammer energy in these correlations is not clearly understood yet, and thus it is still not practised in many developing countries. This study highlights the importance of hammer energy in N-value corrections and studies the effect of hammer energy on soil properties like low strain shear modulus and state of denseness. The influence of different SPT corrections is studied, along with the impact of including energy measurements in analyzing the correlation between the SPT N and low-strain shear modulus.

***Keywords*:** Subsurface Investigation, SPT, N-values, Shear modulus, Correlation

1. Introduction

Standard Penetration Test (SPT) is the most widely used field test in soil investigation projects. This test classifies subsoil layers in terms of penetration resistance (N-value), i.e., the number of blows needed to cause the sampler to penetrate the last 30 cm of total 45 cm penetration, using the driving weight of 63.5 kg falling over an anvil from a drop height of 75 cm. It is helpful when undisturbed sampling is difficult, like gravelly, sandy, silty, and sandy clay soils. SPT is often used to approximate the in-situ density and angle of shearing resistance of cohesion-less soils and the strength of cohesive soils. The samples obtained help in the identification of different subsurface layers, and N-values can be used for geotechnical design purposes, as several dynamics and static properties of subsoil layers with well-established correlations [1]-[3].

Because of the importance of SPT as a primary in-situ test in geotechnical engineering, it is essential to study the factors which affect the results. Energy Transferred by hammer blows (E_H) to the sampler is observed to be the most important factor affecting N-values [1][3] and is considered in designs as hammer energy correction factor. An increase in E_H will lead to a linear reduction in N-values and vice versa. Thus, if the E_H for N-value is unknown, a correction factor based on standard recommendations or previous experience will not be appropriate and may lead to erroneous estimation of subsurface properties.

In India, N-values are used to estimate most design parameters for geotechnical design through existing correlations, irrespective of their applicability to the region. These correlations are developed using data acquired at a specific E_H and in a particular region. It is imperative to study the influence of E_H while deriving different subsurface properties using N-values. Moreover, it is also observed that E_H variations influence the termination depth of borehole or the rebound layer, which is often considered a resting layer for foundations. Thus, ambiguity in E_H may also lead to the selection of a weaker soil layer for foundation construction. Hence, in this study, the influence of E_H on low-strain shear modulus (G_{max}) and soil's state of looseness or denseness is discussed.

2. Correction to recorded SPT N-values

SPT N-values measured in the field are affected by several variables, such as the operation of hammer dropping, length and verticality of guide rods, hammer–anvil dimensions and weights, sampler type, and hammer blow rate. Apart from these, unavoidable site factors are groundwater table, fines content in soil and depth of soil layer being tested. These variables are accounted in the analyses using several correction factors. Common corrections are overburden pressure correction (C_N), hammer energy correction (E_h), borehole diameter correction (C_2), sampler liner correction (C_3) and rod length correction (C_4). E_H accounts for the efficiency of the blows given by the hammer for the theoretical maximum energy which is estimated from the height of the fall and the weight of the hammer. For dry boreholes, the corrected standard blow count for 60% E_H $(N_1)_{60}$ is widely calculated using the relation [4]

$$(N_1)_{60} = E_h C_2 C_3 C_4 C_N N \tag{1}$$

Bowles [4] suggested correction as unity for the case of a small borehole, no sample liner and drill rod longer than 10 m. Thus, the measured N-value must be corrected only for E_H and the overburden pressure. However, Indian code IS 2131 [7] uses outdated correction factors for overburden pressure. Seismic design code IS 1893 [8] recommends assumed hammer energy correction factor for liquefaction without accounting for important correction factor for Hammer Energy. The authors found that these correction factors are not developed for major soil types in India but are still widely used in practice for all geotechnical designs.

2.1. Importance of Hammer Energy Correction

Several early studies showed the dependence of blow count on E_H. Schmertmann and Palacios [9] showed experimentally that the measured blow count was inversely proportional to the energy delivered to the drill rods for blow counts less than 50. Seed et al. [10] suggested that measured blow counts (N-value) be corrected to reference energy of 60% for liquefaction studies. This analysis was based on the liquefaction studies using famous safety hammer with rope and cathead release. Hence, E_H standardization was proposed at the 60 % level per regional practices.

The energy correction factors for equipment in different countries were first reported by Skempton [11] and later updated by Anbazhagan et al. [1][3]. The method of release has a significant effect on the efficiency of the hammer. Thus, the energy correction factor is highly dependent on local practice and should not be generalized. Further, the selection of energy correction based on equipment type only is also not appropriate, as E_H variation is site-specific [12]. Anbazhagan et al. [2] showed that energy values vary significantly within the same depth and soil. Thus, a generalized approach to account for energy variations is debatable because it does not consider differences in the specifications of the SPT equipment, which are known to affect the transferred energy significantly.

For the same soil conditions, an SPT hammer with lower energy efficiency would result in a higher SPT N number than a higher energy efficiency SPT hammer. Thus, the N value should be standardized to a site-specific energy level using correction factors to reduce the variability of the SPT N-values due to the considerable variation in the energy delivered. The standardization will enable uniformity among the in-situ soil properties correlated to the measured N-values [5]. Considering this, one must verify the minimum energy measurements required for a borehole based on variations in SPT. It may not be sufficient to adopt the minimum ASTM [13] and BS [14] codal recommendations for the number of readings. It may be advised to continue the energy measurement for all the blows as it has significant variation, which the authors also observed in recent research [3][6].

3. Correction to recorded SPT N-values

The state of soil, i.e., loose or dense, is interpreted based on N-values. This interpretation also affects borehole termination depth. Generally, boreholes are terminated when a very dense soil/weathered rock layer is reached, defined by SPT N-values more than 50 or 100, depending upon the regional code provisions or tender documents. Table 1 presents the most widely used soil states for sands as a function of N_{60} given by Terzaghi and Peck [15]. If these recommendations are followed without knowing the applied energy to measure SPT N-values, the interpretation of denseness of soil changes completely. For example, if N-value of 20 is measured at 30% ER, then medium dense soil can be interpreted as dense or very dense soil (see Table 1).

Table 1: State of sandy soils according to N_{60} values (after Terzaghi and Peck [15])

In-situ State	N_{60}	Measured N-values for energy transfer ratio (ER, %)			
		30	40	50	70
Very loose	0-4	0-8	0-6	0-4.8	0-3.43
Loose	4-10	8-20	6-15	4.8-12	3.43-8.57
Medium	10-30	20-60	15-45	12-36	8.57-25.71
Dense	30-50	60-100	45-75	36-60	25.71-42.86
Very Dense	>50	>100	>75	>60	>42.86

The authors observed that the measured N-values are often directly used as N_{60} in Table 1, or a standard energy value is assumed based on previous experience or code recommendations [7]. Suppose the energy transfer ratio (ER = ratio of actual delivered E_H to the theoretical maximum potential energy) values are much lower, e.g., 20-30%. In that case, there is a danger of overestimating the denseness of the soil state. As discussed previously, considering an ER of 30%, if a rebound is considered at N-value of 50, the actual corrected N value is 25, which corresponds to Medium relative density as per Table 1. Thus, a lower ER value will give a higher N-value and lead to early termination of the borehole much before the desired termination depth. This misjudgment of soil state will have severe consequences if the selected rebound layer cannot bear the load of the structures built later.

As seen in Fig. 1, soil samples obtained from a recent Standard Penetration Test (SPT) were collected by using a single-barrel drilling method in rebound layers at depths of 6.5-8m and 8-9.5m, where the N-values exceeded 100. However, the samples do not appear to be hard or dense, indicating that using N-values as the sole termination criteria for boreholes without considering the energy ratio (ER) may lead to an unreliable soil investigation.

Fig. 1. Photos of samples obtained at rebound layers in this study

4. Correlations with Low Strain shear Modulus

N-value is the most used parameter to estimate soil properties required for foundation design, site response, and liquefaction hazard estimation. Many empirical relationships have been developed between N-value and soil properties measured in lab or field. Some common soil parameters which are determined using correlations with N-values are friction angle (∅), cohesion (c), elastic modulus (E), Shear wave velocity (V_S), Low strain shear modulus (G_{max}), Poisson's ratio (μ), Density (γ), Relative density (D_r), Bearing capacity & Settlement.

It may not always be feasible to determine shear wave velocity (V_S) and low strain shear modulus (G_{max}) in-situ using seismic methods because of space constraints and high noise levels (often in urban areas).. Therefore, it becomes necessary to determine these dynamic properties through indirect methods such as correlating with SPT N-values. Schmertmann [16] stated that shear modulus depends on the soil's dynamic stress-strain properties and the strain level in the travelling shear waves. Penetration of sampler during SPT involves dynamic shear behavior at the failure reference level of shear strain and modulus. Hence a correlation between N-values and maximum shear modulus at low strain can be expected [4]. Anbazhagan et al. [1][3] reviewed all SPT N versus G_{max} correlations, highlighted popularly used correlations' limitations, and gave updated correlations. It was found essential to select a correlation that should consider local site SPT testing practice and prevalent ER imparted by the SPT hammer.

The authors observed that most correlations were obtained based on studies in Japan, with E_H different from the other regions, thus limiting their applications. To account the variation in E_H values, modification factors for the equation were presented. Anbazhagan et al. [3] reevaluated the modification factors for the correlation to be used for different ER values and validated them using field-acquired Crosshole and downhole data. The updated equation and modification factors to be used for different ER values is discussed below

$$G_{max} = 16.40 {N_{78}}^{0.65} \quad \text{(MPa)} \tag{2}$$

N_{78} is the SPT blow count corrected for 78% ER. As discussed, the data used for the development of correlation was adopted from Japan with ER 78%. Hence, N_{78} is used in the equation. Fig. 2 shows the G_{max} estimated for different ER values as per equation 2.

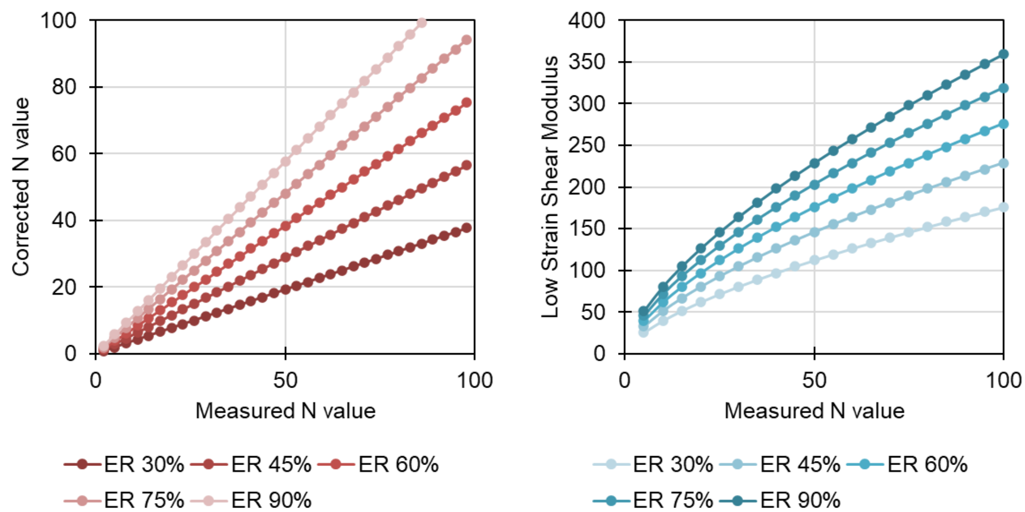

Fig. 2. G_{max} values estimated for measured N at different ER values (after Anbazhagan et al. [3])

Equation 2 can be modified as follows to account for changes in ER:

$$G_{max} = 16.40 {N_{78}}^{0.65} = 16.40 \times \left(CF_{(78\ to\ ERm)} \times N_{ERm}\right)^{0.65}$$

Correction factor for N-value:

$$CF_{(78\ to\ ERm)} = \frac{ER_m}{78} \tag{3}$$

The general form of the equation for measured energy ratio ER_m:

$$G_{max} = a_m {N_{ERm}}^{0.65}$$

Modified coefficient a_m for ER_m

$$a_m = 16.40 \times \left(\frac{ER_m}{78}\right)^{0.65} \tag{4}$$

For example, if ER_m is 60%, then the equation will be $G_{max} = 13.83{N_{60}}^{0.65}$.

5. Conclusion

In this study, the influence of SPT hammer energy (E_H) on the determination of rebound layer and low-strain shear modulus has been discussed. Rebound criteria were studied to understand the role of E_H measurement in establishing refusal/rebound strata. The rebound depth in SPT was found to be dependent on the energy delivered from the hammer to the sampler. Lower ER values resulted in shallow rebound depth as the N-value becomes higher, which could lead to severe overestimation of soil stiffness and shear strength. Energy variation was observed to affect the estimation of G_{max} significantly. Modification factors to use G_{max} correlation for any ER value were discussed, and its difference from regular N-value correction was highlighted. It was concluded that conducting SPT without energy measurement and further interpreting the subsoil properties leads to significant errors in design.

Acknowledgements

The authors thank SERB, DST, Govt. of India for funding the project "Development of correction factors for standard penetration test N-values in India through energy measurement and field experiments – Step towards a reliable Liquefaction Potential Assessment" Ref: SERB/F/198/2017-18 dated 11/05/2017."

References

[1] P. Anbazhagan, A. Parihar, and H. N. Rashmi, “Review of correlations between SPT N and shear modulus: A new correlation applicable to any region,” Soil Dynamics and Earthquake Engineering, vol. 36, pp. 52–69, 2012.

[2] P. Anbazhagan, A. Uday, S. S. Moustafa, and N. S. Al-Arifi, “Correlation of densities with shear wave velocities and SPTnvalues,” Journal of Geophysics and Engineering, vol. 13, no. 3, pp. 320–341, 2016.

[3] P. Anbazhagan, A. Kumar, S. G. Ingale, S. K. Jha, and K. R. Lenin, “Shear modulus from SPT N-values with different energy values,” Soil Dynamics and Earthquake Engineering, vol. 150, p. 106925, 2021.

[4] J. E. Bowles, *Foundation analysis and Design*. New York: McGraw-Hill, 1996.

[5] Aggour, M. S., & WR, R. (n.d.). (rep.). Standard Penetration Test (SPT) Correction. Report no. MD02-007B48, The Bridge Engineering Software And Technology (Best) Center, Department of Civil and Environmental Engineering: University of Maryland, College Park, MD 20742.

[6] P. Anbazhagan, M. E. Yadhunandan, and A. Kumar, “Effects of hammer energy on borehole termination and SBC calculation through site-specific hammer energy measurement using SPT hema,” Indian Geotechnical Journal, vol. 52, no. 2, pp. 381–399, 2022.

[7] IS 2131, “Indian standard method for standard penetration test for soils (first revision) reaffirmed 2002”. Bureau of Indian Standards, New Delhi, 1981

[8] IS 1893 – Part 1, “Indian Standard Criteria for Earthquake Resistant Design of Structures Part 1 General Provisions and Buildings”. Bureau of Indian Standards, New Delhi, 2016

[9] J. H. Schmertmann and A. Palacios, “Energy Dynamics of SPT,” Journal of the Geotechnical Engineering Division, vol. 105, no. 8, pp. 909–926, 1979.

[10] H. B. Seed, I. M. Idriss, and I. Arango, “Evaluation of liquefaction potential using field performance data,” Journal of Geotechnical Engineering, vol. 109, no. 3, pp. 458–482, 1983.

[11] A. W. Skempton, “Discussion: Standard penetration test procedures and the effects in sands of overburden pressure, relative density, particle size, ageing and overconsolidation,” Géotechnique, vol. 37, no. 3, pp. 411–412, 1987.

[12] W. D. Kovacs, L. A. Salamone, and F. Y. Yokel, “Energy measurement in the standard penetration test,” 1981.

[13] ASTM D4633, “Standard test method for energy measurement for dynamic penetrometers”. ASTM International, West Conshohocken, PA, 2016, https://doi.org/10.1520/d4633-16

[14] BS EN ISO 22476-3:2005+A1:2011, “Geotechnical investigation and testing, Field testing, Standard penetration test”. British Standards Institution (BSI), London, 2006.
[15] K. Terzaghi and R. B. Peck, Soil Mechanics in Engineering Practice. New York, N.Y: John Wiley & Sons, 1967.
[16] J. H. Schmertmann, “Use the SPT to measure dynamic soil properties?—yes, but..!,” Dynamic Geotechnical Testing, ASTM STP 654, pp. 341–355, 1978.