

Equations to Correct SPT-N Values Obtained from Using Non-Standard Hammer Weight – Part II

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ABSTRACT

SPT-N was thought-up to estimate soil parameters throughout correlations. It has standard hammer freely drops under its own weight. The theoretical energy wh is standard. Practically, measured applied energy varies from 35% to 90% of " wh ". If In-Situ hammer became lighter, the obtained N-counts mislead. Effect of changing hammer weight on N-measured insufficiently investigated. Thus research question raises revealing unclosed gap. Hypothesis of linear relationship between, w and N could not be taken for granted. A physical model has been designed and manufactured to simulate SPT-rig. It has ability of changing hammer weight, drop height and efficiency levels. Six efficiencies are investigated. Five hammer weights are changed. Reconstituted well graded dry dense sand characterized the soil. It has been found that relationship between hammer weight and blow counts is linear. The line slope is function of efficiency. Empirical equations and curve were suggested to correct the incorrect N-values.

RÉSUMÉ

L'énergie théorique « $W.H$ » de cet essai est standard. Selon l'expérience, l'énergie appliquée mesurée varie de 35% à 90% de « $W.H$ ». Si le marteau de l'essai in-situ devenait plus léger, les nombres de coup N obtenus seront trompant. L'effet du changement de poids du marteau sur N -mesuré n'est pas suffisamment examiné dans la littérature. L'hypothèse d'une relation linéaire entre, W et N , n'a pas pu être considérée comme acquise. Un modèle physique a été conçu pour simuler l'essai SPT. Il a la capacité de changer le poids du marteau, la hauteur de chute et les niveaux d'efficacité. Six efficacités ont été étudiées. Cinq poids de marteau ont été changés. Un sable étalée dense sec est reconstitué pour caractériser le sol. Il a été constaté que la relation entre le poids du marteau et le nombre de coup est linéaire. La pente de la ligne est fonction de l'efficacité. Des équations et courbes empiriques ont été suggérées pour corriger les valeurs N non standard.

1 INTRODUCTION

The standard penetration test, SPT is part of every soil investigation program mainly for cohesionless soils where samples are disturbed. So, a sample is unable to provide mechanical properties. If the only advantage of SPT is predicting in-situ density of a stratum, this is enough to be acknowledged. Not to mention, its advantages when it comes to prediction of strength and deformation parameters. Simply, SPT test is a spoon driven into soil stratum, the cumulative blow counts N that consumed for penetrating this stratum one feet deep is reported. Then N normalizes and correlated to soil properties. The test is first announced by Terzaghi (1947), then, every geotechnical code wrote a clause for SPT-Standards.

This research is not focused on the correlation between the blow counts N and soil properties. The main concern is taking hold of the correct blow counts, not just any blow counts. Previous experience shows evidences of a non-standard hammer weights had been used. Also, some of SPT-rigs show poor energy efficiency ratios, ER. The non-standard hammer weight and the rig efficiency, both, presenting the theme tune of the current paper.

This study is an experimental study. It is based on laboratory physical model to simulate the SPT rig and performed on reconstituted well graded dry dense sand as the foundation soil media. This research is an extension to previously published two papers in the same topic and has practical advantages.

2 LITRETURE REVIEW

The literature review consists of six headings presenting three main subjects. It starts with energy ratio definition and normalization, $(ER)_{60}$. Then, the equations used to correct the obtained blows count N_m obtained from the usage of non-standard hammer weight introduced and discussed. Finally, the previously published two technical papers written by the authors on the topic discussed.

2.1 The Adjective Term Standard

The idea of standard penetration test is a standard weight freely fallen down from a standard height on the top-tip of a rod several times until driven its spoon a standard depth, ASTM D1586-99 (1999). The above simplification shows three constants gave the test adjective-term standard. Namely, they are fixed weight, fixed height, and fixed depth. If any of these three constants change, the measured N deviates and the results do not worth the term standard.

2.2 Normalization of N_m for $(N_1)_{60}$

Fang (1999) recaps the normalization practice to adjust the measured blow counts N_m to be $(N_1)_{60}$ based mainly on Eq. 1, as shown here-after:

$$(N_1)_{60} = N_m \times C_R \times R_{S/C} \times (ER)_{60} \times C_N \times C_S \quad [1]$$

Where $(N_1)_{60}$ is normalized blow counts, N_m is in-situ measured blow counts, C_R rod correction adjustment, $R_{S/C}$ adjustment for hammer and sampler sizes, $(ER)_{60}$ normalized energy ratio, C_N overburden adjustment, while C_S is sampler linear adjustment, R_S and R_C for cohesionless and cohesive soils, respectively. If the hammer weight and the hammer drop height are the standard values, values of R_S and R_C became unity.

Tokimatsu and Seed (1987), presented the effective overburden pressure adjustment C_N , however C_N should not exceeds 1.5 as maximum. The Liner adjustment factor C_S varies from 1.10 to 1.25 if no liner is used. If liner is used C_S became unity.

2.2.1 Energy Ratio Normalization

The energy ratio ER is the ratio of the measured hammer efficiency, E_m to theoretical free-fall hammer efficiency, E_{th} . The Normalized energy ratio $(ER)_{60}$ is the ratio of the measured hammer efficiency, E_m to 60% of the theoretical free-fall hammer efficiency, i.e. 60% E_{th} . The free-fall theoretical energy, E_{th} of SPT-Hammer weighs w freely drops under its own weight from a height h is:

$$E_{th} = \frac{1}{2}mv^2 = \frac{1}{2}wv^2 = \frac{1}{2}w(\sqrt{2gh})^2 = wh \quad [2]$$

Where m is the hammer mass, v is the fallen velocity and g is the acceleration. The In-Situ applied energy that denoted by E_m has been measured and usually found to be smaller than the theoretical energy E_{th} , in average about 50% of E_{th} . It presents the efficiency of hammer system and it's over all components. In that case, the normalized energy ratio $(ER)_{60}$ is as follows, e.g.:

$$(ER)_{60} = \frac{E_m}{E_{th}} = \frac{50\% E_{th}}{60\% E_{th}} = 0.83 \quad [3]$$

Skempton (1986) is the first who suggested standardizing the results of hammers having varying efficiencies to be accounted to 60% efficiency. The term ER in Eq.1 suggested to use CE instead of $(ER)_{60}$. The typical practical ranges for CE are 0.5:1.0 Donut hammer, 0.7:1.2 Safety hammer and 0.8-1.5 Automatic hammer.

Rami (2013) presented a study to evaluate the energy efficiency of Donut and Safety hammer used in Egypt. The study is based on a comparison between N-values measured from SPT to back calculate N-values abstracted from cone penetration test CPT. The obtained results show that the energy efficiency is 50% and 60% for Donut and Safety hammer, respectively. Accordingly, the energy correction factors "CE= $(ER)_{60}$ " is 0.82 and 1.0 for Donut and Safety hammers, respectively that are used in Egypt. These values seem to be high.

2.2.2 Significance of $(N_1)_{60}$ Normalization

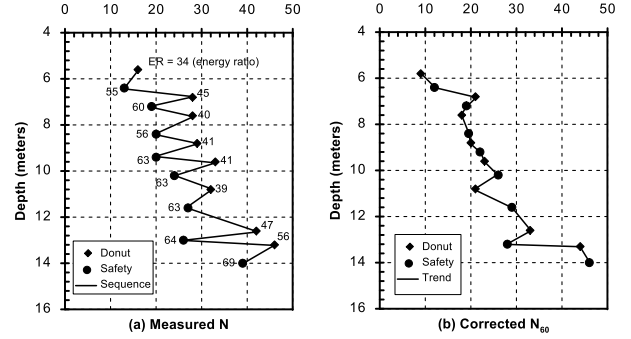


Figure 1. SPT N-values vs. depth where - (a) uncorrected data and (b) corrected to 60% efficiency.

The FHWA NHI-06-088 (2006) recommended to adjust the measured N_m to be $(N_1)_{60}$. Figure 1 shows two SPT-tests results conducted by donut and safety hammers inside one borehole. The energy ratio ER measured and found to be 45% for donut and 60% for safety hammer. Graph (a) shows individual trends of the measured values N_m for both hammers. A consistent profile is obtained as shown in graph (b) once data were corrected to be $(ER)_{60}$.

2.3 Correction for Using Non-Standard Parameters

The hammer weight w , height of drop h , penetration depth L and sampler diameters D are the test constants that are possibly deviated and need corrections. Burmister (1948) proposed Eq. 4 based on the principal of super position for correcting the measured N_m to be N_{cr} if all or one of up-mentioned parameters deviated. The formula assumed the behaviour of w and h variation is linear.

$$N_{cr} = N_m \frac{(W \text{ lbs}) (H \text{ in})}{(140 \text{ lbs}) (30 \text{ in})} \frac{[(2.0 \text{ in})^2 - (1.375 \text{ in})^2]}{D_o^2 - D_i^2} \quad [4]$$

Where; N_{cr} is the corrected number after using non-standard parameters, N_m is the In-Situ measured number of blows, W , H , D_o and D_i are the nonstandard hammer weight, height of drop, outer and inner diameters of the sampler, respectively.

Lacroix and Horn (1973) improved Eq. 5 by overlooking the effect of sampler inner diameter D_o but added the effect of spoon penetration depth deviation, L_i . Again, the equation behaviour is the same as Eq 4, i.e. the behaviour of w and h variation is linear.

$$N_{cr} = N_m \cdot \left(\frac{2 \text{ in}}{D_i}\right)^2 \times \frac{12 \text{ in}}{L_i} \times \frac{W_i}{140 \text{ lb}} \times \frac{H_i}{30 \text{ in}} = \frac{2 N_m W_i H_i}{175 D_i^2 L_i} \quad [5]$$

Lamb (2000) replaced the 140 lbs hammer by a custom-made one of 100 lbs, and then the energy

transferred was measured. The efficiency ratio has been reduced from 90% to 66%, i.e. reduced by 27% while W has been reduced by 29%, no wide difference, i.e. linear behaviour is acceptable approximation.

2.4 Gap, Hypothesis and Research Question

The previous studies have not suggested convinced procedures to correct the measure blow counts N_m , when the used hammer weight is non-standard. The suggested equations such as Eq. 4 and Eq. 5 are not closed form nor empirical or based on physical models. They tend to be based on engineering logic. Never the less, there existed nothing better. This gap needs to be closed.

It is believed here-in, that the overall rig efficiency affects the measured blow counts N_m . As the efficiency decreases i.e. old machines, the N_m increases, i.e. overestimated N_m . This hypothesis needs to be verified.

Based on the above shortage this research has been planned to answer the following questions:

1. If the hammer weight W is reduced to its half, will N_m be doubled? For example!
2. Is the relationship between W and N_m linear? If so, is the line slope function of the rig efficiency?
3. Is it reliable to use a physical model as a methodology to answer the above inquiries?

The above research questions present the theme of the current work as well as its focus. The third one of them is a key question and could not be answered without giving it a try. Accordingly, a pilot study forced itself.

2.5 Pilot Study and Premature Model

Khater (2016) carried out a pilot study to investigate the ability and reliability of constructing and then using physical model in such type of problems. An earliest small physical model, first of its kind, has been manufactured and then used owing a single energy ratio; ER equal to 100%, i.e. no energy loss. Several hammer weights have been used and the corresponding blow counts reported. After a simple analysis, Eq.6 has been given to correct the number of blows measured from the usage of non-standard hammer weight.

$$N_{Std} = \eta_K \left(\frac{W_f}{W_{Std}} \right) N_f \quad [6]$$

Where N_{Std} is the corrected number of blows due to the use of non-standard hammer weight, W_f is the weight of non-standard hammer, W_{Std} is the standard hammer weight, N_f is the measured number of blows due to the use of non-standard hammer weight and η_K is a correction factor its value depends on the system efficiency. In this case, i.e. ER equal to 100% η_K value is unity.

The pilot study gave initial answers for questions 1 and 2. The answer of question number 3 was very clear and final; the physical model is capable of handling this type of research works. Accordingly, the main paper started, finished and published as it will be seen in the next sub-title.

2.6 Mature Model and Introductory Study

Khater et al. (2019) conducted an experimental study based on the above mentioned pilot study. A physical model has been designed and manufactured to simulate the behaviour of the SPT-test. The model has the ability of changing hammer weight, drop height, and efficiency levels. Starting from perfectly smooth ER = 100% up to extremely rough ER = 35%. Throughout that work only two efficiencies were investigated as efficiency borders, i.e. ER = 100% and 35%. Five different hammer weights have changed to generate the qualitative data that is analysed throughout that study.

Reconstituted well graded dry dense sand SW characterized the used soil. Load cell and computer software have been used to control energy levels and blow counts. Then, analytical numerical study has been performed and discussed.

It has been found out that the relationship between hammer weight and blow counts is semi-linear, in both efficiencies, but the line slope reduced from 1.0: 1.0 to 1.0: 0.5 as the efficiency reduced from 100% to 35%. That conclusion explained why $\eta_K = 1.0$ in Eq. 6, pilot study. Also, physical models technique could be used quite-well to simulate the behaviour of the SPT-test. Moreover, the authors suggested useful empirical equations and curves to adjust incorrect N-values to their standard correct values, with good accuracy, for the two studied efficiencies, in addition to practical recommendations.

The current paper presents an extension to the previously published paper, Khater et al. (2019). It studies extra four efficiencies in addition to the previous studied two efficiencies. A total of six efficiencies have been presented, namely they are ER = 100%, 85%, 70%, 60%, 50% and 35%.

The same physical model and the same foundation soil have been used here and in the previously published paper. Accordingly, here-in a summary of the model and the soil properties will be introduced. For more details about both the previous paper is published and reported throughout the enclosed list of references, to save space.

3 METHODOLOGY METHOD AND TOOL

Two expressions, methodology and method are closely interlocked. They serve two different roles. Simply, the methodology describes the strategy and outlines the way in which research to be carried out. Method is the tool which will be used to create the needed data to answer research question. Methodology demands the methods to generate convincing data. With one methodology, several methods may be used to compensate research hypothesis and achieve its goal. In writing-up research methodology comes first, in order.

3.1 Methodology or Thesis Strategy

The paper main idea is a SPT-rig used non-standard hammer weight W_f , hence produced incorrect blow counts N_f . Is it possible to predict the correct number of blow counts N_{Std} from the knowledge of W_f , N_f ? As mentioned

earlier, Eq. 6, the correction factor η_K is a function of the rig efficiency and this is something to be measured and not to be calculated. The expected strategy must be experimental, either full scale or physical model. Throughout either of them, the hammer weight W_f and the rig efficiency ER well be changed in turns as a counter. If the choice is full scale, it is costly and time consuming but the main disadvantage is the soil. It is up to be impossible to perform all tests in the same identical soil. The results will not be consistence and hard to be analyzed or connected. Logically, the methodology is experimental and the method is physical modeling.

3.2 Why a Physical Model

The physical model is one of the early methods that are used to simulate the behaviour of a full-scale object by building a smaller one, i.e. to-scale. Usually, it is not used to measure proportional values, due to the scale effect. But its results are representative, when it comes to prediction of empirical relations or explanation of behaviour. The research question forces the method to go to a physical model. The question is what is the trend or the empirical equation of the curve related different hammer weights W_f with corresponding blow count N_f ? Also, how do the machine efficiencies induces from the above mentioned curve, a family of curves? This needs to work on several SPT-machines with different efficiencies, and each having capability of changing the hammer weight. The soil media must be homogeneous and constant. These circumstances lead to physical model.

3.2.1 Physical Model: Description

Figure 2 shows 2D and 3D “Solids” drawing of the model. The model description had been fully reported and explained by Khater et al. (2019). Briefly, the model consists of ten main parts; namely they are frame, sand tank, driven tube, smooth roller bearings, frictional-breakers, anvil, guides, hammers, load cell, digital converter and others tiny parts.

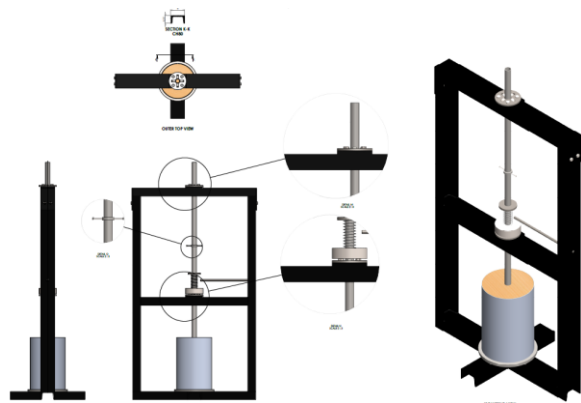


Figure 2. The physical model 2D – 3D “Solids” schmatic

The Model idea is; a hammer weigh W_i lifted up manually to a pre-defined constant height “H”. Then, it

freely falls down under its own weight repeatedly knocking a steel rode several knocks until pushing it inside the sand tank a certain distance “h”. The number of knocks is the bow counts N_{mi} . Then, W_i changes to be W_{i+1} and so on and so far, the test repeated for five different W 's. The model efficiency controller has the ability of changing efficiency level. Within this paper, six efficiencies have been considered, 100%, 85%, 70%, 60%, 50% and 35% they covers the maximum, minimum possible efficiency limits and in between.

The driven tube that stand for SPT-spoon, is made of steel has internal / external diameters of 15.71/22.86 mm, respectively with a tiny tip of an arrow shape. Multi-function movement guides have been used. They are frictionless roller bearings that are used during 100% efficiency. Later on, they were replaced by manual frictional breakers to activate and increase resistance that reduces the efficiency level down to 35%. Two pair of these multi-function kits have been mounted on top and at middle of the model frame to secure the tube verticality. Also, guides have been soldered to the driven tube to get full control on the hammer fallen height and the tube penetration length. A load cell, having pair of strain gages, Wheatstone bridge and digital converter are used.

3.2.2 Physical Model: Efficiencies Adjustment

This article presents the used method to adjust the different efficiencies. First, the frictionless bearings are attached, then a hammer weighs 9.12 N freely drops a height of 10.0-cm several times until the driven tube penetrates the sand tank by 15.0-cm. The total number of blow counts is $N_{th-total}$. Then, the smooth bearings are replaced by frictional breakers. These breakers have the ability to apply adjustable lateral pressure with uniform roughness along the surface area of the driven tube top. The total number of blows $N_{m-total}$ has been increased to achieve the same penetration depth, i.e. 15.0-cm. The weight W , the drop height h , the penetration depth L are the same in both cases, i.e. with and without friction, but the consumed energy for penetrating the same depth is not the same because the number of blows increased for the case of frictional bearing. To equate the two energies, the energy of the frictional bearing should multiply by a factor η_K less than one, Eq. 7 and Eq.8.

$$w \times h \times N_{th-total} = \eta_K \times w \times h \times N_{m-total} \quad [7]$$

$$\eta_K = \frac{N_{th-total}}{N_{m-total}} \leq 1.0 \quad [8]$$

Here η_K is the system global efficiency. By trial and error the applied lateral pressure is adjusted several times until $\eta_K = 0.35$, i.e. efficiency 35%. The same procedures repeated to all the used efficiencies, that is to say, 85%, 70%, 60% and 50%.

3.2.3 Physical Model: Experiment Procedures

The sand tank is filled with compacted sand of thin layers to create a homogeneous soil mass. The sand reached the possible maximum dry density 18.3 kN/m^3 and is kept constant during the rest of all tests. The efficiency controller adjusted to the desired efficiency, i.e. any one. Next, the chosen hammer that weighs W_i is mounted 10.0-cm a head of the driven tube upper tip. This height is kept constant during the test and adjusted after every blow. However, the hammer keeps knocking the tube tip repeatedly until the tube penetrates the sand by 7.50-cm; at this stage, no number of blows is counted. Then, the guide is re-adjusted to let the tube penetration depth equal to 15.0-cm. The test continues and the 15-cm penetration depth is achieved and the number of blows is counted, N_i . For accuracy, the penetration depth corresponding to every single knock is measured too. The results of the load cell recorded. Every experiment has been audio and video recorded. The rate of the hammer dropping was seven blows per minutes, in-average. This is one single test. The total number of tests was 30-case.

3.2.4 Physical Model: Quality Control

A load cell has cantilever shape bolted to the model frame from one side and its free tip touches the bottom side of the anvil. It has two strain gages glued on the tension and compression sides of the cantilever. The load cell has been tested and calibrated. Every time the hammer hits the anvil, the data-logger records a reading. The load cell serves as quality control kit to observe the model behaviour. It counts the number of blows, recording the rate of blows and observing the applied force variation.

3.3 Cases of Studies and Data Generation

Thirty five cases of studies have been performed to create qualitative data style. As shown in Table 1, five different hammer weights have been used regarding the investigated efficiencies. Each efficiency is first adjusted, e.g. $\eta_K = 70\%$, then five different hammer weights have been used, 5.59 N, 9.12 N, 19.07 N, 26.62 N and 42.37 N. This cycle presents cases study from C- 16 to C- 20. This cycle repeated seven times to cover $\eta_K = 35\%$ to $\eta_K = 100\%$. It is assumed here-in, that W_5 is presenting the standard hammer weight of the real SPT-rig, theoretically speaking. This means the non-standard hammer weight all the time is smaller, this is the practical assumption.

Table 1. Cases of studies for different efficiencies, $\eta_K\%$

weight (N)	W_1	W_2	W_3	W_4	W_5
$\eta_K = 35$	C- 01	C- 02	C- 03	C- 04	C- 05
$\eta_K = 50$	C- 06	C- 07	C- 08	C- 09	C- 10
$\eta_K = 60$	C- 11	C- 12	C- 13	C- 14	C- 15
$\eta_K = 70$	C- 16	C- 17	C- 18	C- 19	C- 20
$\eta_K = 85$	C- 21	C- 22	C- 23	C- 24	C- 25
$\eta_K = 100$	C- 26	C- 27	C- 28	C- 29	C- 30

W_i the hammer i weight in Newton; η_K Model efficiency in %
C-01 Case study 01, C-19 Case study 19, etc.

3.4 Soil Sample Properties

This section introduces the performed laboratory routine tests used to determine the properties of the soil intended to be used and fills the sand tank of the model. Briefly, a natural sand soil has been used to create a reconstituted well graded sample, SW. then the physical and the mechanical properties have been determined, measured and then used during the course of the study, item 3.3. All the laboratory tests were per ASTM Book of Standards. Then, all the tests results have been reported in Table 2.

The principal of constructing the reconstituted sample, is to re-accommodate a pre-determine weight of a specific particle diameter in its correct sieve. Table 2 shows the retained weight on each sieve that satisfies the well graded sand conditions, SW.

Table 2. Reconstitutes soil sample properties, SW

¹ Sieve number	16	20	30	40	50	100	200
Opening, mm	1.18	0.85	0.6	0.43	0.30	0.15	0.075
% Retained, by weight	40	18	12	8	6	8.5	7.5
² Sieve constants	$D_{10}=0.19, D_{30}=0.6, D_{60}=1.18, C_u=6.21, C_c=1.81$						
³ Densities	$\rho_{d-(max)} = 20.1, \rho_{d-(min)} = 16.0, \rho_{d-(used)} = 17.0, D_r=0.6$						
Shear parameters	$\Phi = 36^\circ$ with $\rho_{d-(used)}$, $\alpha = 29^\circ$ with $\rho_{d-(min)}$						

¹ASTM system, ² D's in mm, ³ ρ_d 's in kN/m^3 .

The authors suggest denoting this sand as "Fayoum" sand, Fayoum is the city where the sample abstracted from. This suggestion has two benefits, for researchers using numerical techniques the given values here are trustable and preventative. On the other hand, for researcher using experimental techniques Table 2 could be used as it is, and saving a lot of time. Fayoum is Pharaohs name and the Pyramids foundation soil is sand.

4 PRESENTATION OF RESULTS

Throughout the rest of this work, the terminology efficiency is defined same as the definition of energy ratio ER. To recap, ER is the ratio of the measured hammer efficiency E_m to theoretical free-fall hammer efficiency E_{th} . Accordingly, 100% efficiency means no energy losses, as an example, while 35% efficiency presents rough system with energy losses up to 65% of the total theoretical applied energy. As shown in Table 1, six efficiencies ER have been physically modeled. Namely they are 100%, 85%, 70%, 60%, 50% and 35% to model perfectly

smooth, extremely rough machines and in between. As shown in Figure 3, the results of the same efficiency, ER are gathered, connected to build-up an experimental curve consists of five measured points, Table 1. These five points indicate five different weights of the fallen hammer presented as five ratios for dimensionless presentation. The x-axis presents the changing weight ratios while y-axis presents the corresponding number of blow ratios. The six cases of ER are plotted and each curve presented as the best fit.

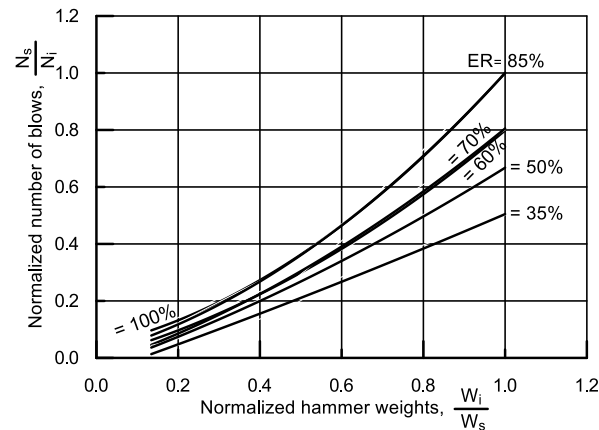


Figure 3. Blows counts vs. hammer weight for six different efficiencies ER, Axes normalized and curves best fit.

4.1 Axes Normalization

To generalize the use of Figure 3 curves, the absolute values were avoided and the normalized values have been adopted. The largest weight and its corresponding number of blows have been considered as reference values, i.e. datum's. Accordingly, x-axis co-ordinates are W_i/W_s , y-axis co-ordinates are N_s/N_i while i increases from 1 to 5. W_s is the largest used weight while N_s is the lowest blow counts, which all the time corresponding to W_s . This normalization system generalize the use of the curves and also make the ratios ranges from 0.0 to 1.0, this is practical and logical range.

4.2 Reading the Curves

Figure 3 displays six curves, they present efficiencies ER of 100%, 85%, 70%, 60%, 50% and 35%, descending order. It is obvious in all cases, as the ratio W_i/W_s decreases, N_s/N_i decreases too. This says if the used hammer is lighter than the standard one the measured N_i is over estimated and hence misleading, hammers weight wise. Same observation spreads for efficiencies, as ER decreases; N_i increases too, efficiency wise.

Generally, for the same W_i/W_s if ER decreases N_s/N_i decreases too, i.e. N_i increases and dramatically. Moreover, at W_i/W_s equal to 1.0, i.e. the standard hammer is used, if ER decreases N_s/N_i decreases. In other words, N_i increases and overestimated. This is over looked by many designers and is considered a non-seen harm.

The relationship between W_i/W_s and N_s/N_i is linear at low values of ER and lightly curved at the theoretical values of ER, i.e. 100%. The slope of each curve is function of its efficiency ER. Accordingly, considering the relationship between W_i/W_s and N_s/N_i is linear and the line slope decreases with the decrease of the efficiency ER is an acceptable practical approximation, so far.

4.3 Advantages of Figure 3

The six curves drafted within Figure 3, have two advantages. First, they explain the problem behavior and the factors affecting it, descriptively. Refer to item 4.2 for more details. The second and the main advantage is the correction of the measured N_m values due to the usage of non-standard hammer weight, numerically,

Assume the standard hammer weight is W_s and the wrong used hammer weight is W_i . Thus obtained value of blow counts induced using W_i is N_i . Based on the calibrated machine energy ratio is ER pick up the curve, then calculate W_i/W_s ratio. Then intersect the chosen curve and turn to the left to intersect the Y-axis to get the corresponding N_s/N_i . As N_i is known, the N_s could be calculated from the obtained ratio. This N_s is the corrected value of the well-known term N_m . This is a simple and direct procedure to solve major field problem.

One may agree or disagree about the degree of accuracy of the obtained result of N_m . The results are obtained from physical model; this needs intensive filed tests for verification. Again, it is more or less an approximation, guide values and encouraging for further and future research work. It may be better improved.

5 ANALYSIS OF RESULTS

Figure 3 could be used for the correction of N_i , but it needs to be physically available in hand. Also, one cannot use computer's software such as Excel or so to manage easy and accurate calculations. Due to this shortage Figure 4 has been presented.

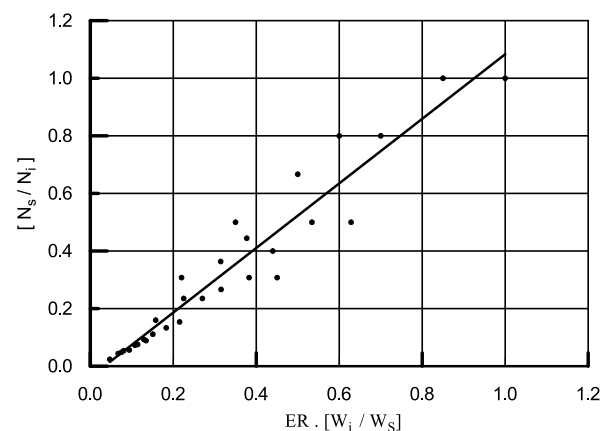


Figure 4. Blows counts ratio vs. hammer weight ratio normalized for six different efficiencies ER, lime best fit.

Figure 4 is a modified version of Figure 3. First, the values of ER = 100% have not been ignored even it is not practical but it will not deviate the results.

The y-axis is the same as before, while the x-axis is the hammer weight ratios, W_i/W_s multiplied by the energy ratio ER. It means every weight ratio has been multiplied by the corresponding ER, i.e. the x-coordinate of cure ER=60% has been multiplied by 0.6 and so on and so far for all the cases of study. Then Figure 4 has been drafted and the line best fit has been performed. Accordingly, the empirical Eq. 9 is as follows:

$$\frac{N_s}{N_i} = 1.12 \left(ER \frac{W_i}{W_s} \right) - 0.04 \quad [9]$$

ER is the energy ratio, i.e. ratio of the measured hammer efficiency, E_m to theoretical free-fall hammer efficiency. It should be noticed it is a real number and not percentage when used in Eq. 9. Also, the resulting N_s should be rounding and presented as integer number, i.e. as an example $N_s = 24.01 = 24.99 = 24.0$ for softly. Eq. 9 is general and can be used for any value of ER and any value for W_i/W_s , even if $W_i/W_s > 1.0$ because it is straight line equation.

The 1st author believes from engineering sense and formality shape Eq. 9 should be re-written as following, "Khater Equation":

$$\frac{N_s}{N_i} = 1.04 \left(ER \frac{W_i}{W_s} \right) - 0.04 \quad [10]$$

Figure 3, Figure 4, and Eq. 10 could not be used without the knowledge of ER value. This is not available for many SPT-rigs. This makes the above equations and figures useless, or one may assume value for ER. Instead of letting un-expert one to assume such value, Figure 5, may help to solve the problem if ER is not known.

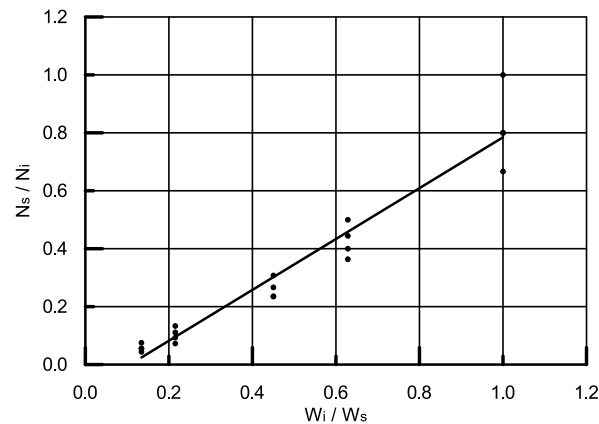


Figure 5. Blows counts vs. hammer weight for average efficiency ER, Axes normalized and curves best fit.

Figure 5 is the same as Figure 3, except the readings of ER=100% and 35% have been ignored. It means the values of ER= 50%, 60%, 70% and 85% only considered. Then, Figure 5 has been drafted and the line best fit has been performed. Accordingly, the empirical Eq. 11 is as follows:

$$N_s = 0.88 \left(\frac{W_i}{W_s} \right) N_i \quad [11]$$

This empirical equation could be used as a first approximation when ER is not available. It is valid within average practical range of ER, i.e. 50% to 85%

6 CONCLUSIONS AND RECOMENDATIONS

This final heading contains three subtitles. The first is evaluation and self-criticism. The second is the conclusions and main findings. The third is recommendations and suggestion for practice and further research works.

6.1 Achievement or Complete Failure

Within article 2.4, the authors stated the gap needs to be filled in literature, the hypothesis and three research questions. It is needless to say, if one of them has not been answered and satisfied, it will be complete failure.

The gap in literature shows, no convinced procedures to correct the measure blow counts N_m , when the used hammer weight is non-standard. Here-in, Figure 3. Eq. 10 and Eq. 11 are the desired procedures.

The hypothesis believes that the overall rig efficiency affects the measured blow counts N_m . As the efficiency decreases the N_m increases, i.e. overestimated. True hypothesis and proved, Figure 3.

The first research question was; If the hammer weight W is reduced to its half, will N_m be doubled. The answer is no, not exactly, see Eq. 11. The second research question was; Is the relationship between W and N_m linear?, the answer is yes and the slope of the line affected by the machine efficiency. The third question was; Is it reliable to use a physical model as a methodology to answer the above inquiries?. Yes and perfect methodology.

The paper title is; equations to correct SPT-N values obtained from using non-standard hammer weight. The text matches the title and the equations have been given.

6.2 Conclusions and Main Findings

- The rig overall efficiency ER greatly affect the measured number of blows N_m .
- As the rig efficiency decreases, the measured number of bows N_m increases and misleading, i.e. over estimating the soil properties.
- The relationship between weight of the hammer W and the measured number of blow counts N_m is linear but the slope of the line decrease as the

- efficiency decreases and leads again to over estimating N_m .
- d. The incorrect number of blows that induced from the usage of nonstandard hammer weight could be corrected. One figure and two questions have been suggested to do so, Eq. 9, Khater equation is helpful with great trust, and Eq. 10 is approximate and could be used as a first approximation.
 - e. It is strongly recommended to force by the power of low every SPT-Machine to have regular calibration and must be certified and the efficiency ER must be reported in every geotechnical reports contract with it.
 - f. The physical model is effective to explain the behavior of such problem. Its numerical results could be used if it is in a dimensionless forms

6.3 Further Research Work

It is suggested to extend this study to investigate the effect of changing the drop height on N_m . Also, a field work is needed to verify and correct the modeling results. If the finite element is used as a 3D-dynamic problem, this will be a new contribution.

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