HAMMER ENERGY CALIBRATION OF STANDARD PENETRATION TEST

Final Year Project UG - 2018

By

Capt Hilmi (Syn Ldr) (NUST201439295BMCE10114F)

Capt Ahmad Arslan (NUST201439286BMCE10114F)

Capt Hasnain Saeed (NUST201439273BMCE10114F)

Capt Waqas Matloob (NUST201439341BMCE10114F)

Capt Usman Shahid (NUST201439274BMCE10114F)

Military College of Engineering, Risalpur

National University of Science & Technology Islamabad, Pakistan

2018

This is to certify that the

BE Civil Engineering Project titled as

HAMMER ENERGY CALIBRATION OF STANDARD PENETRATION TEST

SUBMITTED BY

Capt Hilmi (Syn Ldr)	(NUST201439295BMCE10114F)
Capt Ahmad Arslan	(NUST201439286BMCE10114F)
Capt Hasnain Saeed	(NUST201439273BMCE10114F)
Capt Waqas Matloob	(NUST201439341BMCE10114F)
Capt Usman Shahid	(NUST201439274BMCE10114F)

Has been accepted towards the partial fulfilment of the requirement for

BE Civil Engineering Degree

Lt Col Dr. Mazhar Iqbal

Military College of Engineering, Risalpur

National University of Science & Technology Islamabad, Pakistan

Dedication

Our worthy instructors for their unquantifiable love and their support,

Our beloved Parents for their unquantifiable love and their support,

and to our Project Advisor and Co Advisor for sharing their wisdom and guidance

and encouraging us to complete this project successfully.

Last but not the least, to our Institution and home for providing us with such platform.

ACKNOWLEDMENTS

First, we would like to thank the Almighty Allah because whatever we are, whatever has been achieved by us is solely due to Him alone.

We would like to express our very great appreciation to our supervisor Dr. Mazhar Iqbal Arshad and co-supervisor Dr. Kamran Akhtar for their valuable and constructive suggestions during the planning and development of this work, as well as their invaluable guidance throughout this Endeavor.

Finally, we wish to thank our parents for their support and encouragement throughout our study, and the love they have shown to us in this life. Without them we would not be here.

All Syndicate members

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The Standard Penetration Test (SPT) is the most widely held in-situ test used for subsurface exploration and investigation. There are number of factors that affect the efficiency of the SPT system. The most dominant of them all is hammer efficiency. This research aims at finding the actual amount of energy transferred by the hammer with respect to the standardized 60 percent. For the purpose of reducing the major variations of the N value due to large differences in the values of energy transferred, it is suggested that N value should be changed to specific energy level by the use of certain correction factors. As per this study, these correction factors are different for the type of equipment used.

Keeping in view all the previous work done, a system named as Standard Penetration Test Energy Measurement and Analysis Tool (SEMAT) has been developed which gives the energy ratio of the actual energy transferred to the theoretical energy using accelerometers (for velocity) and strain transducers (for force) which are mounted on indigenously developed instrumented SPT rod. Actual energy transferred is calculated by the SEMAT using force velocity method whereas theoretical potential energy (mgh) is calculated manually and inserted to the software.

Study incorporated field tests behind Civil Engineering wing MCE on different borehole depths. Equipment used in the test was the property of MCE Geotechnical laboratory. Major causes of loss in hammer energy in manual method are sliding of hammer and tilting of SPT rods. With each blow of hammer strike data is acquired from the accelerometers and strain transducers which are connected to compact Data Acquisition device which convert analog signal into digital data and gives the output on tough book in the form of acceleration, strain, velocity and force waveforms.

A good data shows proportionality of force and velocity waveforms. Results were compared with the results of Pile Driving Analyzer (PDA) on the same site and the energy ratio of both the tests was almost similar to each other. The average energy ratio of MCE Geotechnical laboratory equipment came around 34 percent against the normalized 60 percent. Which means that it is around 57 percent out of 100 percent. Which means that blow count of every SPT test conducted on above mentioned equipment must be multiplied by 0.57 to get actual count of SPT N value. Which lead us to assume a FOS of around 4 for geotechnical designs based on SPT N value. During the conduct of tests, it was also observed that energy ratio increases with increase in depth up to 10 meters.

SEMAT is recommended to be used on variety of SPT equipment being in service in Pakistan. For sensitive building designs Automatic SPT method should be used. In future, calibration should be carried out using foiled strain gauges instead of strain transducers and results be compared. Furthermore for depths greater than 5 meter some instrumented assembly could be developed that could be placed just above the sampler so as to get the actual energy transferred in the sampler instead of SPT rod.

Chapter 1

INTRODUCTION

1.1 Background

Soil testing for the attainment of several geotechnical requirements are being carried out by several methods and reliable geotechnical procedures. Standard Penetration Test (SPT) also known as " In-situ penetration test " of soil is considered to be the most popular and widely used procedure by virtue of its simplicity in operation and economy. It is primarily being used for the cohesion less soils which cannot be easily measured. The standard penetration test determines the SPT N value (the number of hammer blows required to drive a sampler are referred as standard penetration number, N value) which is very important by virtue of its index of soil liquefaction and dynamic properties which gives an indication of the soil strength and stiffness and can be empirically related to many engineering properties. It is considered to be the basis of the site response and micro zonation studies as well.

Procedure followed is driving a standard sampler into a soil to a predefined distance (450 mm/18inch) using a standard hammer (630N/140Ibs) from a standard drop height (762 mm/30 in) and recording the blow counts. First count is neglected due to drilling disturbances of soil, last two counts are added to get NSPT.

One of the predominantly influencing factors in maintaining accuracy of the results from standard penetration test is the Energy Ratio (Er) and N value (penetration resistance) which is to be used for the quantitative evaluation of foundation for comparing results.

There are various factors which effect the SPT N value of which most important is the energy delivered to derive a sampler, because of various mechanical energy losses in SPT system the actual energy does not become equal to the theoretical energy. Earlier in SPT the N value was used directly from field which influenced the overall results moreover several types of SPT equipment's were used to conduct the test and the efficiencies as per the sophistication in technology, influence the N value. Another important parameter found is N60, for this the researchers have deduced that the rod should be normalized to the 60 % of the theoretical potential energy, N60.

Now the question arises is that how this energy is measured and the energy ratio is calculated. First and the foremost step in measuring acceleration and strain transferred to the rod. It is recommended in studies that the precision of accelerometer and the strain gauge should be better than 2% of the measured value.

The energy ratio is the actual energy measured upon initial impact of the hammer compared to the theoretical energy expressed as percentage. $Er = E(measured)/E(theoretical) < 100\%$. A totally compliant frictionless hammer would have an energy ratio of 100 %, the energy loss would only be due to variables associated. Energy losses are mainly due to the frictional losses moreover the potential losses are either because of impact on anvil depending upon its mass, the type of machine, skills of the operator and other characteristics. Following are the variables which adversely affect the results:

a. Drop Height
b. Drop weight
c. Verticality of the test
d. Grease, dirt, rust
e. Poor contact at joints
f. Type, quality, number and size of rod.
g. Speed of testing
h. Poor winch control

Since most of these variables cannot be controlled practically so we need to devise some energy reduction factor through which we could actually predict the amount of Hammer energy transferred. So that we must know in future that there is some reduction in hammer energy and that reduction is equal to some factor which is less than 1.

The main objective of this project is to design an indigenous low cost SPT hammer energy calibration system for the first time in Pakistan which will be consists of two rods which should be capable of measuring acceleration and force results during the hammer impact. which will be further used to derive the actual energy and Energy ratio (Er).

1.2 Problem Statement

SPT is the major soil investigation test being conducted in Pakistan for soil strength parameters. Unfortunately, due to non-availability of standard calibration system, there are major discrepancies in the test results. Energy transferred is not always the same due to friction in the pulley, variation in drop height, different inclinations of hammer impact and other reasons as that of standard energy. All this leads to major energy losses which need to be calibrated for accurate measurements.

1.3 Objectives

Few of the major objectives of the research work are as follows:

a. To develop SPT Hammer Energy Calibration System with a view to obtain Hammer Efficiency for each blow of SPT test in the field.
b. To develop instrumented SPT rod fixed with:
    i. 2x Accelerometers
    ii. 2x Strain Transducers
    iii. Requisite Data Acquisition System (cDAQ)
c. Determine energy efficiency of hammers during standard penetration test using Manual method.
d. To suggest suitable energy corrections applicable in Pakistan.

1.4 Relevance of Research and Research Questions

Since SPT is used extensively by Geotechnical engineers to determine engineering properties of soils all over Pakistan. There is no tendency of hammer energy calibration by different drilling/ soil investigation companies. A small change in the values may result in inappropriate result of NSPT. With unknown energy efficiency reliability of blow counts of SPT is questionable? This will result in improper parameters for geotechnical design. The research work will be focused to answer following questions.

a. Lack of relevant hardware/software for hammer energy calibration of SPT?
b. What is the main cause of hammer energy loss in SPT?
c. How much is actually the reduction in hammer energy during SPT?
d. What are the best possible procedures to account for variation/loss of Hammer Energy?

Chapter 2

LITERATURE REVIEW

2.1 Historical Background

Due to the dry sample recovery techniques, the standard penetration test came into being. In the past, subsurface investigations were executed mainly through the use of wash borings. A wash boring contains the rotation of water and cuttings from the boring are removed by drilling mud mixture as the hole progressed. First method of dry sample recovery was introduced by Charles R. Gow in 1902. 1 in outside diameter sampling pipe was driven by using 50 kg weight. This method is applied for short span of time. After this method, it was known that the resistance to driving the sampler was affected by the condition and properties (e.g., strength and density) of the soil. Thus, then the number of blows required to drive the sampler at a given distance is defined by the terminology "penetration resistance".

The split spoon sampler with outside diameter of 2 in was introduce by the Sprague and Henwood company of Scranton, Pennsylvania (Fletcher, 1965). Harry A. Mohr and Gordon F. A. Fletcher standardize few details regarding the procedure soon after this sampler was introduced. The details standardized included: (1) driving the split spoon sampler by dropping a 63.5 kg (140 lb.) mass a distance of 76.2 cm (30 in); and (2) the standard penetration resistance or "N" value was defined as the number of blows required to drive the 5.08 cm (2 in) outside diameter sampler a distance of 30.48 cm (12 in). This procedure was further standardize in the mid-1950 's where the N value was defined as the Number of blows required to produce the last 12 of 18 inches of penetration [Fletcher, 1965].

Further standardization was carried out by the American Society for Testing and Materials, where they specified that the drill rod should have the stiffness equal to or greater than a steel rod having a diameter of 1-5/8 in or an "A" sized hollow-drill rod. Further reduction in the variabilities of the procedures was introduced by International Commission of the International Society of Soil Mechanics and Foundation Engineering were made [Arce et al., 1971].

Davidson et al., 1999, feature the history of SPT testing and the ASTM standardization of SPT testing from the beginning of the twentieth century till to date in their report of University of

Florida. Their report gives the earliest credits of SPT to Mohr and Terzaghi. SPT is attributed to Terzaghi by SPT Working Party and Hvorsolv acclaims Mohr for evolving the Test in 1927.

2.2 Procedures Affecting the N value

"N" value is the total blow counts required for the penetrate of split spoon sampler 12 inches below the ground after initial 6 inches discarded. Factors that may affect the N value are:

a. Type of hammer

b. Anvil type

c. Depth of drilling

d. Rate of blow

Besides all above, Operational procedures also influence the N values as given in the table below:

Failure to seat the sampler spoon on undisturbed material	N-values obtained are Incorrect
Operators Attitude	N values for the same soil using the same rig can vary, depending upon the operator and his mood during drilling
Gravel plugged introduced in the sampler	This results in higher N value
Method of Drilling	SPT N values are also influenced by the drilling techniques e.g. Mud stabilized vs Cased holes
Unable to achieve free fall of the drive weight	Fall of the drive weight will be restricted if more than 1.5 tons of the rope around the drum are used
Concentrated weight does not applied on the drive cap	N value is increased due to reduction of impact energy
Blow counts and penetration are not recorded accurately	Results into incorrect N value
Drill holes are too large	More than 4 in diameter of drill hole is not recommended, it results into decrease of blow counts

Table 2.1: Operational Procedures

2.3 Energy Measurements in Past Decades

To measure the transfer energy in SPT, different projects were undertaken in past few decades. Tests were conducted in the states of Oregon, Florida, Minnesota and Washington.

2.3.1 Test conducted in Oregon

GRL conducted the test to measure the energy transfer for drill rigs operated by Oregon department of transportation. Nine Oregon DOT rigs were tested at five different soils. There were total ten test holes. The average efficiencies range from 60% to 65% was recorded for test holes with rope and cathead operation. Automatic hammers deliver average efficiencies of 77 to 82%. Furthermore, two Mobile automatic hammers were also tested by GRL. 62 % average efficiency was delivering by hydraulically powered trip hammer. Whereas spooling winch safety hammer deliver efficiency of 48%.

2.3.2 Test conducted in Florida

Davidson et al. conducted an extensive study to access the effect of drill rig variables on energy transfer at the University of Florida. A broad history of the progress of ASTM standard for SPT testing has been published in the report obtained from this study. Average energy transfer in the safety hammer was found to be 68% with the standard deviation of 9.7. Automatic hammer resulted in 83.2% energy transfer with the standard deviation of 6.7. Energy transfer found for the safety on the mobile drill was 43.7% with the standard deviation of 3.1.

2.3.3 Test conducted in Minnesota

As discussed by Lamb (1997) Minnesota Department of Transportation first observed the variability of N value deliver by their state rigs on a project in which two different rigs with different hammer systems were sampling in same soil conditions. There one rig was producing N values consistently higher than the other. This cause them to measure the energy deliver in each rig through pile driving analyzer. They conducted eight tests in different soil types for each of their four hammer systems. Cathead rope system transfer the energy ranging from 61 to 75% with an average of 66%. The energy transfers for CME automatic range from 75 to 94% with an average of 79%.

2.3.4 Test conducted in Washington

In Washington, the Seattle branch of ASCE offered to measure the transfer efficiency of local drill rig hammer systems in 1995 as discussed by LAMB (1997). GRL & Associates perform the test on the drill rigs supplied by Washington department of transportation using pile driving analyzer. Central Mine Equipment (CME) automatic hammers produced an average of 77% whereas cathead rope systems and Safety hammers produced 51% to 75% energy.

2.4 Short Comings of SPT

The delivered energy in drilling system is responsible to produce consistent blow counts in SPT. Variable blow counts are produce by different deliver energies in the same deposit at the same overburden pressure because the SPT blow count is inversely proportional to the delivered energy [Schmertmann, 1975]. The factors which affect the penetration resistance values is to be understood and procedures which reduce the wide difference in delivered energy of drill rigs is therefore necessary.

There are different factors that affect the reproducibility of SPT which include personal, equipment and procedure. Many of them have been standardize and many are not. In addition, it was concluded, based on other studies of SPT, that the blow count results may be significantly influence by the other factors. Palacios, [1977] and Schmertmann, [1975, 1976 and 1979] have summarized these factors as under:

a. The use of drilling mud versus casing for supporting the walls of the drill hole
b. The use of a hollow-stem auger versus casing and water
c. The size of the drill hole
d. The number of turns of the rope around the drum
e. The use of a small or large anvil
f. The length of the depth ranges over which the penetration resistance is Measured

Schmertmann 1979 discuss that once the liner from an SPT sampler is removed, sample recovery is improved but N value is significantly reduced. The procedure of ensuring free-fall is a prime source of inconsistency. Before and during sampling, variable effective stress conditions have important bearing on the test results. When different drill rigs are used, wide variation in the measured delivered energies are found as discuss by Schmertmann and Smith [1977], Kovacs et al., [1975], Kovacs [1979]. An extensive study regarding force and energy dynamics was conducted by Schmertmann and Palacios, [1979]. It was concluded by them.

a. There is an inversely relationship between "N" and ENTHRU (energy reaching the sampler, Ei) to at least N is equal to 50. Maximum of ENTHRU is utilized in pushing the sampler into the soil.
b. ENTHRU may vary from 30 % to 85 % of the free-fall hammer energy. This clearly shows that "N" could vary by a factor of almost three in the same soil due to only one variable, ENTHRU.

It can be deduced from the discussion that has been done so far that soil penetration resistance is affected by certain human and mechanical factor as well as the insitu conditions of the soil. These insitu conditions include soil sensitivity, moisture content, density, shear strength and soil type. It is therefore necessary to understand these factors so that SPT correlations found in the literature can be effectively used. To reduce the effect of these variables, there is a need to further standardize these procedures.

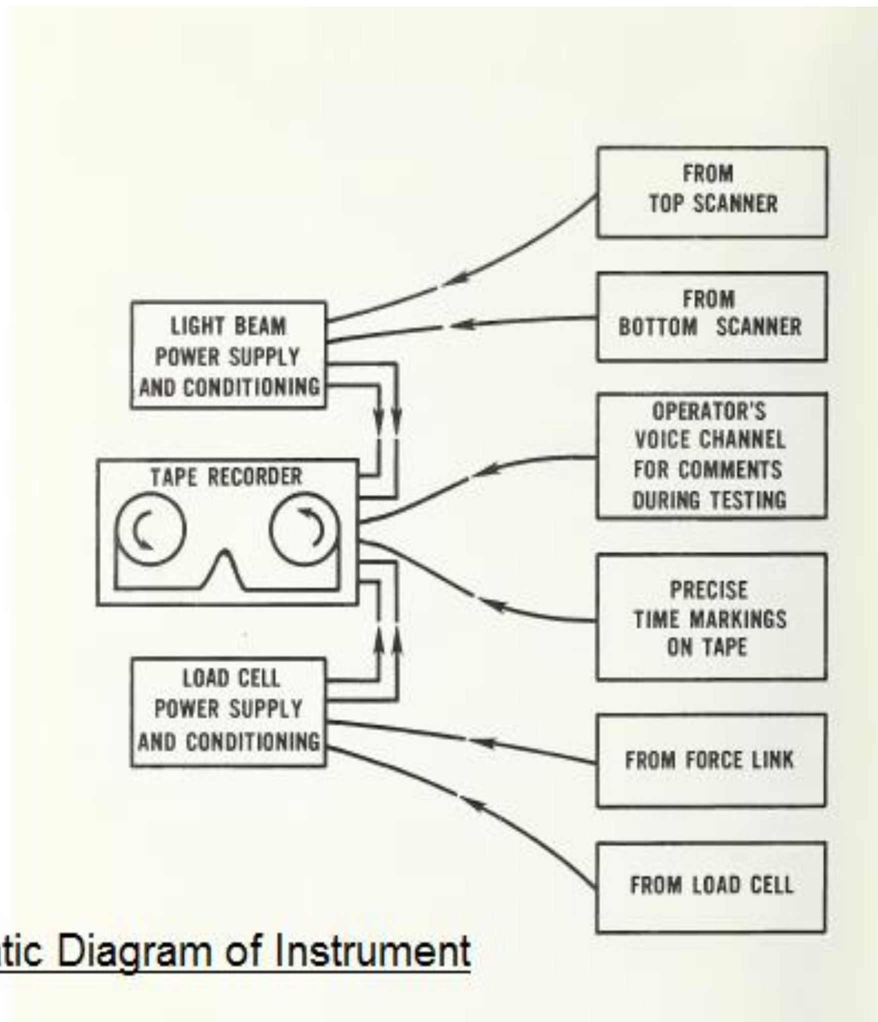
2.5 SPT Role in Standard Penetration

SPT is use by Geotechnical engineers in subsurface investigations for foundation design. It is estimated that 85-95% of these foundation design was accomplished by utilizing the SPT N value. The results from this test are correlated with the soil ability to resist shear failure and excessive settlement. This test also shows changes in the soil profile. It is also use to assess the liquefaction potential of sands. Kovacs et al carried out extensive study in this field. Purpose of their study was:

a. To develop a system that could measure the energy deliver by the drill rigs while performing the SPT
b. To calculate the energy, deliver by the Drill rig system
c. To evaluate the transmission characteristics of different hammer and anvil system

2.6 Instrumentation and Procedures

To measure the hammer velocity and fall height two light beam sensors were fixed above the anvil and to measure the stress wave generated in the drill stem, a load cell with the capacity of 178 KN was installed on the anvil. The proper placement of the scanners made it possible to get a clear view of how the hammer or drive weight moves up and down. The traces from these hammers assisted in measuring the hammer height and instantaneous velocity at any time during stroke. Force time relationship obtained from the load cell was use to find kinetic energy in the drill stem after impact. Schematic diagram of the instrumentation is shown below.



Schematic Diagram of Instrument

Figure 1 Schematic Diagram of Instrument

To measure the cathead rotational speed multiple range hand held tachometer was used. Along with the measurements of drill stem length, the type of hammer and its configurations, the cathead rotation direction was also noted. They obtain the following data from this test:

a. The speed of cathead and its rotational direction
b. Force time history below the anvil
c. Time history of the scanner used to measure hammer position

To calculate the energy, deliver by drill rig system, field measurement system and procedures were developed. In the study energy ratio was defined in a four different ways. One pair takes into account the measured fall height while the other pair of energy ratio takes into consideration and assume fall height. The energy ratio was calculated from the velocity of hammer just before impact or from integration of FORCE TIME relationship. The selection of fall height is not very important as it merely establishes a reference energy to which an actual energy can be compared.

To achieve the best result in term of the energy ratio and ability of the operator to achieve 30 in fall height, it was suggested that a nominal two turns of rope around a cathead are sufficient. The variation in energy ratio calculated from the measured fall height and assumed fall height is 3.2 percent with the standard deviation of 4.1 percent. Since it is with in the expected range of variation of routine testing therefore either definition of energy ratio is acceptable. If safety hammer is using at the depth of 40 foot, 100 percent energy transfer from the hammer to the drill rod is obtained. Based on the study it was suggested that Safety hammer is more efficient in delivering the available energy than the Donut hammer. It was observed that there is a wide variation in measured delivered energies using various drill rig systems.

2.7 Summary

In the summary of energy efficiency as suggested by numerous researchers, Davidson et al. (1999) suggested that the energy transfer ratio for safety hammers with cathead and rope hoisting mechanism can differ significantly. The range of stated values is from 30% to 96%. For automatic trip hammers, the range is lesser, with a low of 60% and a high of 90%. Different correction factors as organized by author given below:

Corrections proposed by Robertson and Wide (1997)

Factor	Variable		Correction
Energy Ratio	Trip or Automatic Hammer Rope and Pulley Safety Hammer Donut Hammer		0.8 – 1.5 0.7 – 1.2 0.5 – 1.0
Rod Length (meters)	Length over 30 m '10 – 30 m '6 – 10 m '4 – 6 m '3 – 4 m	(100 ft) (30–100 ft) (20–30 ft) (13–20 ft) (10–13 ft)	Less than 1 1 0.95 0.85 0.75
Sampler	Without liner With liner: dense sand, Clay With liner: loose sand		1.1 – 1.3 1 1
Bore Hold Diameter	'60 – 120 mm '150 mm '200 mm	(2.5 – 4.5 in) (6 in) (8 in)	1 1.05 1.15

Corrections proposed by Bowles (1996)

Factor	Variable		Term	Correction
Energy Ratio	Trip or Automatic Hammer Rope and Pulley Safety Hammer Rope and Pulley Donut Hammer		n1	1.14 – 1.42* 1 – 1.14* 0.64*
Rod Length (meters)	Length '10 m+ '6 – 10 m '4 – 6 m '0 – 4 m	 (100 ft+) (20 – 30 ft) (13 – 20 ft) (10 – 13 ft)		 1 0.95 0.85 0.75
Sampler	Without liner With liner: dense sand, Clay With liner: loose sand			1 0.8 0.9
Bore Hole Diameter	'60 – 120 mm '150 mm '200 mm	(2.5 – 4.5 in) (6 in) (8 in)		1 1.05 1.15

* where n1=(Er/70) example for ER = 80% – 100% n1 = 1.14 – 1.43

Corrections proposed by Skempton (1986)

Factor	Variable		Correction
Energy Ratio	Trip or Automatic Hammer Rope and Pulley Safety Hammer Donut Hammer		None listed 0.9 0.75
Rod Length	Length over 10 m '6 – 10 m '4 – 6 m '3 – 4 m	(over 30 ft) (20 – 30 ft) (13 – 20 ft) (10 – 13 ft)	1 0.95 0.85 0.75
Sampler	Without liner With liner: dense sand, Clay With liner: loose sand		1.2 1.0 1.0
Bore Hole Diameter	'60 – 120 mm '150 mm '200 mm	(2.5 – 4.5 in) (6 in) (8 in)	1 1.05 1.15
Anvil Size	Small Large		0.6 – 0.7 0.7 – 0.8

Corrections proposed by Seed (1984) per McGregor and Duncan (1998)

Factor	Variable		Correction
Energy Ratio	Trip or Automatic Hammer Rope and Pulley Safety Hammer Donut Hammer		1.67 1 0.75
Rod Length (meters)	Over 10 m '6 – 10 m '4 – 6 m '3 – 4 m '0 – 3 m	(+30 ft) (20 – 30 ft) (13 – 20 ft) (10 – 13 ft) (0 – 10 ft)	1 1 1 1 0.75

Figure 2 SPT Parametric Variables

2.8 An Alternative Method of Measuring SPT

Schmertmann and his co-workers at the University of Florida conducted a comprehensive theoretical and experimental study of the statics and dynamics of the SPT (Schmertmann, 1978 and 1979; Schmertmann and Palacios, 1979). They used strain gauge load cells near the top and bottom of the drill rods to measure the force-time histories of the stress waves. This data was further used to compute energy transfer in the rods and the energy loss in the sampling procedure. They concluded that the rods and hammer remain in contact only until tension cutoff happens. This point i.e. tensions cutoff point marks the arrival of the tensile wave reflection from the sampler to the anvil, and stops further transmission of energy from hammer to rods. Since the hammer rod contact time is longer in longer drill rods so greater is the amount of energy that enters the rods. By integration of the measured force squared within the time limits of the first compression pulse times a rod material constant, energy in the rod was calculated as shown in Eq. 1

$$E_n(t) = c/EA \int F^2(t)dt \qquad \text{-----------} \quad \text{Eq (1)}$$

a. Where c is the velocity of longitudinal wave propagation in the rod
b. A Is the cross-sectional area of the rod
c. F(t) is the measured force at a point in the rod.

Velocity of longitudinal waves in the Steel rod is 16800 feet/second and E is 10000 ksi. They concluded that because of energy loss to heat during hammer impact as well as energy trapped in the anvil, the energy in the rods or ENTHRU was less than the hammer impact energy, and it was this ENTHRU, not the energy in the hammer at impact, that produced the sampler penetration that determined the SPT N value. Field data was collected and showed which depicted that N value varies inversely with the energy delivered to the rods. Schmertmann and Palacios (1979) presented two theoretical correction factors to the measured ENTHRU values so that the corrected energies present the ideal case of an infinitely long rod and can be used for comparison between different rod systems. The two factors account for the fact that the rods have a finite length and the measuring point in the rods is some distance below the anvil. These two factors affect the result in apparent cut off times less than the ideal cut off times which results in the multiplication factors greater than one.

Binary Instruments, Inc. (Hall, 1982) has developed SPT energy calibrator that is commercially available. The system developed by them consists of a load cell attached near the top of the drill rods and a data processing instrument which computes the energy at the transducer location in the rods. The transferred energy for each hammer blow is read directly from the instrument as a percentage of the theoretical free fall hammer energy. This calibrator uses Eq. 1 to calculate the energy in the rods and requires cross sectional area of the rods as an input.

While comparing the energy performances of a new automatic hammer and a string-cut free fall safety hammer in their study, Riggs et al. (1983) reported problems with the SPT calibrator. Their measured energy values were irregular with some recorded energy ratios well over 100 %. They subsequently recommended the need for "calibration of the calibrator".

Kovacs (1984), in a discussion to Riggs et al. (1983), suggested that the inconsistent calibrator energy values could be due to premature tensile wave reflections in which case the apparent integration time would be too short, resulting in too low an energy value or hard driving compression reflections from the sampler where integration time would be too long, yielding too high an energy, both of which would produce impractical integration times for calculating the energy in the rods. It thus indicates the importance of knowing the actual integration time that can be used while calculating the energy from Eq. 1.

To study the effect of soil type on the input energy in the drill rods Bosscher and Showers (1987) directed a wave equation analysis of the SPT. When they calculated the transferred energies from Eq. 1 they found that these energies were much higher than the kinetic energy of the hammer at impact. This irregularity again demonstrates the problem in using the force integration method to calculate energy and in choosing the duration of the first compression pulse for subsequent use in Eq. 1.

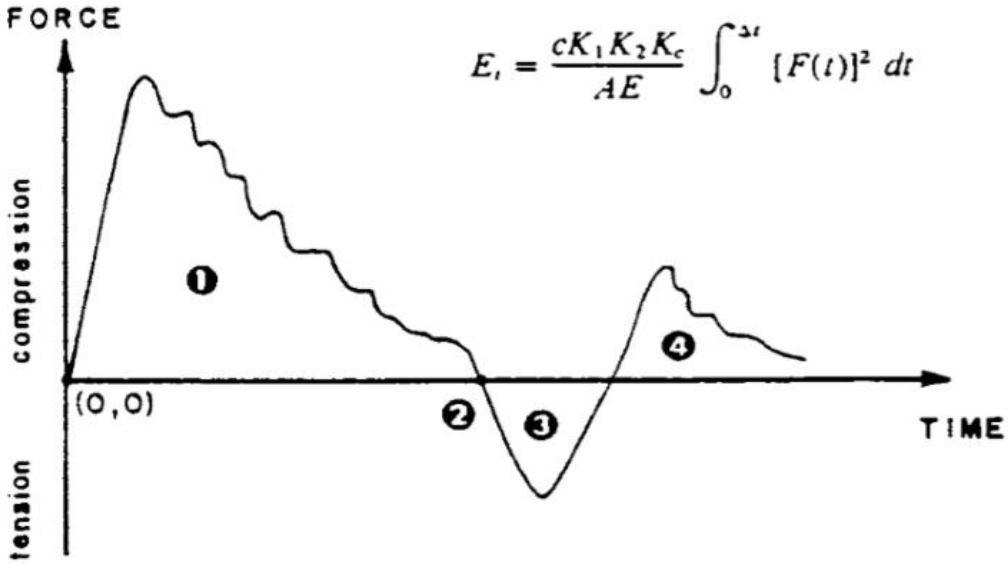
ASTM 04633-86 describes the method to measure SPT energy based on the Schmertmann's force measurement concept. In this method a load cell is attached near the top of the drill rods and force time history is measured during hammer impacts. An ideal force-time waveform as recorded by a load cell is depicted in figure 1. Energy is calculated by applying three correction factors to the equation shown in fig. 1. Kl and K2 are applied to correct for the location of load cells in the rods and their finite rod length, respectively, and are similar in principle to Schmertmann and Palacios' (1979) correction factors. The third factor, Kc, in equation is applied for the correction of theoretical wave speed, c, to the so-called "actual" wave speed, c'. Schmertmann (1982) introduced this stress wave speed correction in 1982 when he was carrying out his SPT calibration work for the Florida Department of Transportation.

There is an assumption made that the total duration of the first compression pulse (see Fig. 1) is the "actual round trip" time that is taken by stress wave to travel from the load cell that is at top of the drill rods to the bottom of the sampler and return back to the same position, and the Kc correction is based on this assumption. The theoretical round trip time is 2L/c, where L is the length of the SPT rod and sampler system below the load cell and c is the theoretical wave speed.

Whereas, invariably, the "actual" pulse duration was always found to be greater than the theoretical time, which showed that “actual" wave speed in the rods was less than 16,800 ft./sec. Hence the Kc factor is used to address this issue by matching the theoretical time duration with the actual compression wave duration. We can simply say that the measured pulse duration is set equal to 2L/c', in which c '=c Kc being the "actual" wave speed in the rods with Kc less than unity here. Riggs et al. (1984) specified that this correction causes the complete force trace to be contracted or compressed along the time ordinate. He claimed that the longer trip time was not because of a slow stress wave velocity but because of secondary compression return at the tail of the curve. He therefore proposed that the theoretical trip time needs not to be adjusted during energy calculations. Only compression tail or deviation beyond that time needs to be reduced.

They however, admitted that they did not have enough evidence and data to support their claim. Sy et al. (1991) later on showed that the theoretical 2L/c actually corresponds to the time interval between the peak force and the tension cut-off point, not from the start of the force trace to the cut-off point as is commonly assumed, therefore use of Kc factor is unnecessary.

Sy et al. (1991) described an alternative method of SPT energy measurement in their study. The method was based on measuring the force and acceleration time histories in the drill rods while conducting the SPT. Time integration of force times velocity was done to calculate the transferred energy. It was shown that the approach adopted by them was more vital and it avoided the inadequacies in the method that included the integration of force data only and was prevailing during that time frame. Field data was presented for comparison between the both methods.



NOTE—1 = First compression pulse or wave
2 = Cutoff time at the arrival of the first tension pulse, at $\Delta t = 2L'/cK_c$
3 = First tension pulse (reflected from the penetrometer)
4 = Second compression pulse (reflected from the anvil)

Fig. 1. Idealized Force-Time Waveform Recorded by Load Cell in SPT Drill Rods (After ASTM D 4633-86)

Table 2: Idealized Force -Time Waveform Record

For calculating energy in a rod due to hammer impact, the force velocity integration method as given in equation 2 is more vital method.

$$E_n(t) = W = \int F(t)\ V(t)\ dt \qquad \longrightarrow \qquad \text{Eq (2)}$$

The maximum value calculated from this equation is the maximum energy transfer in the drill rod at the measuring point. Eq (2) is independent of the force velocity proportionality assumption essential to Eq (1). It neither requires input of E, A or c and nor the input of integration Time which are needed in the existing Force integration method as given by Eq (1). This simple FORCE-VELOCITY methodology to Energy measurement is not new and is, in fact, the standard practice in dynamic monitoring of piles during driving (ASTM D4945-89).

A better insight into the dynamics of SPT is obtained through Force and Velocity data and it provides more fundamental method for calculating energy transfer in the rod. It was shown by the field measurements that the initial velocity peak better defines the point of impact rather than the initial force peak and the theoretical time (2L/C) corresponds to the time interval between initial velocity peak or force peak and the tension cut off point. It was proposed that the stress wave speed correction factor K_c is Needless in calculating ENTHRU.

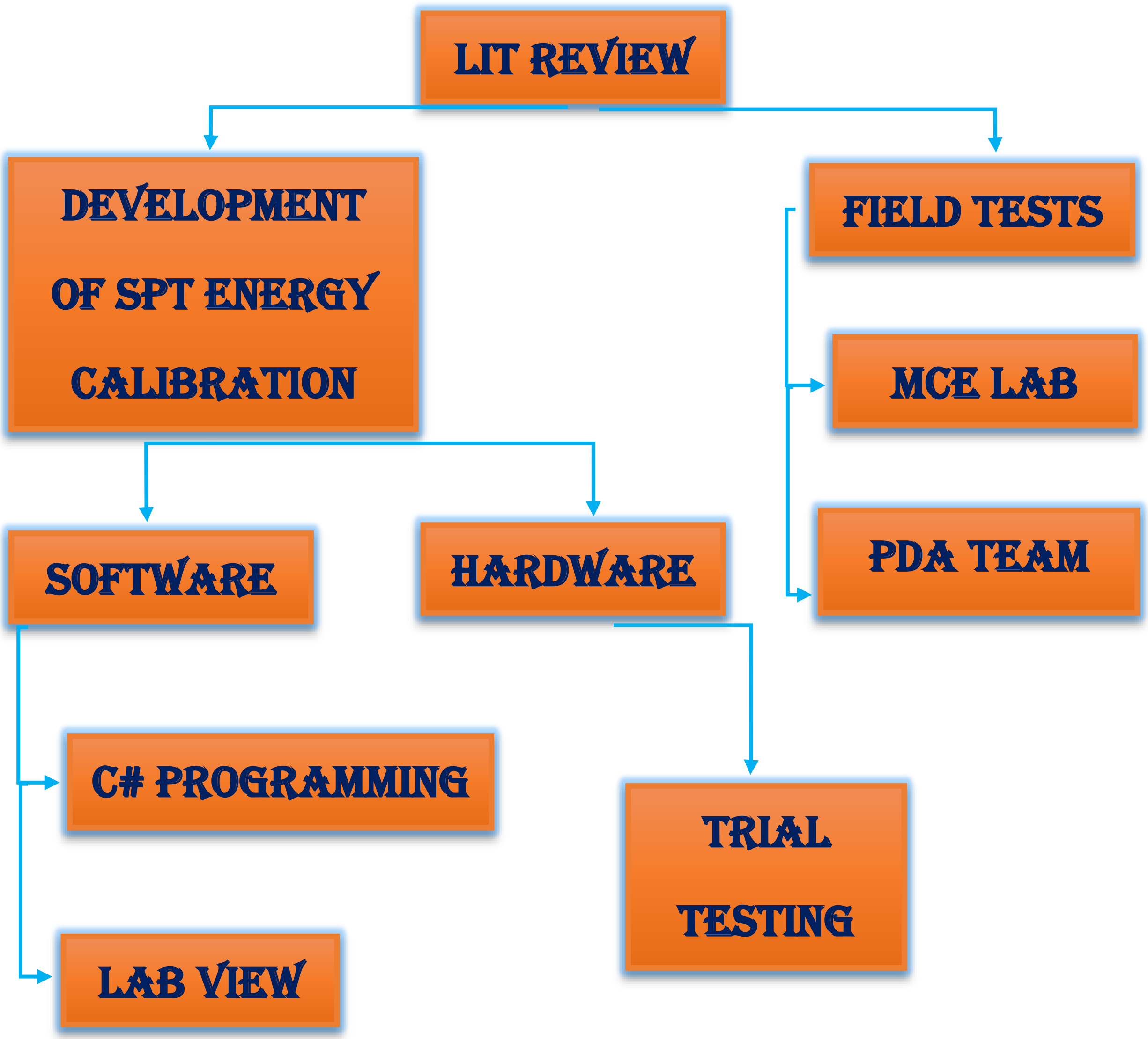
Field measurement also suggested that force integration method provides only approximate ENTHRU values which can be low depending upon the changes in cross sectional area in the actual anvil-rod-sampler system. To measure the energy in the rod, an alternative method based on force and acceleration measurement was suggested. It was suggested that force velocity method was the more rationale as it does not require predetermination of integration time and difficulty of selecting one cross sectional area.

Chapter 3

METHODOLOGY

3.1 Steps Involved

Methodology used for the project is explained below: -



3.2 System for Energy Measurement

We required a mechanism which would measure the transmitted energy of hammer to the SPT rods. For this we are using 2x accelerometers to obtain velocity data and 2x strain gauges to get force measurements. This equipment is capable of recording and displaying strain, acceleration, force and velocity waveforms as well as measuring energy value using FV method.

3.3 Detail of Instruments

A brief description of all the necessary instruments used is provided as under:

3.3.1 Rod

Rod used for this testing is 2.72 feet long with 1.67in outer and 1.27in inner diameter which was locally manufactured. Its size is same as that of size of SPT rods. Threads are provided on both sides inner surface for fixing with SPT rod on lower side and Guide rod on the upper side. Two Piezo Resistive accelerometers and two Strain transducers screwed opposite to each other 2.36in below the top (which is 2.5 times the diameter as per ASTM), on to the mild steel as shown in the figure attached below.

3.3.2 Sensors

Two type of sensors were used namely Strain transducers and Piezo Resistive Accelerometers which are discussed in detail as:

a. Strain transducer

Details of Strain transducers used are as follows:

Developed by	Pile Dynamics Incorporation (PDI)
Effective Gage Length	2.99in
Size	(4.96 x 1.38 x .43 in)
Material	Aluminum
Circuit	Full 350 ohm Wheatstone bridge
Cable	Shielded, available in standard length 41.73in (for cabled connection)
Nominal Sensitivity	380 με/mV/V
Strain Range	Nominally 3,000 με (functional to 8,000 με)
Shock Range	Nominally 5,000 g
Natural Frequency	greater than 2,000 Hz
Temperature Range	-50° to 120°C operating
Attachment method	Bolts to pile

Table 3.1: Strain Transducer

b. Piezo Resistive Accelerometer

Details of Accelerometer used are as follows:

Developed By	Pile Dynamics Incorporation (PDI)
Mounting	Inside custom aluminum block (1.77 x .98 x 1.18 in)
Circuit	Full Bridge
Cable	Shielded, standard length 900mm (for wired connection)
Sensitivity	Nominally 0.07 mV/g with 6.4 V.D.C. input
Range	10000g (limit 20000g)
Temperature range	-12°C to 55°C operating
Attachment method	Bolts to pile

Table 3.2: Accelerometers

3.3.3 Connections

Following was the color Code of the Strain Bridge which was connected through Souriau 851-06-JC1050698 which conventionally named as MS3116J1098P of the MIL-DTL-26482 specifications.

Name	Detail	Color Code
A	+Excitation	Red
B	-Excitation	Black
C	-Signal	Green
D	+Signal	White
E	Shield	
F	not used	

Table 3.3: Connections

These receptacles made by Souriau, France, were not available due to export control policy of France. Thus these were purchased from a Chinese manufacturing company Taixing HangJie Electronic Co., Ltd which custom made MS3116J1098P receptacles. These receptacles are then attached to a CAT 5 Cable further to NI – cDAQ 9223.

Two different approaches were taken, first was to incorporate .Net language supported measurement studio made by National Instruments and second was to use National Instruments Lab-View software. As shown in figure. The Calibration sheets of the 2 x Accelerometers is attached.

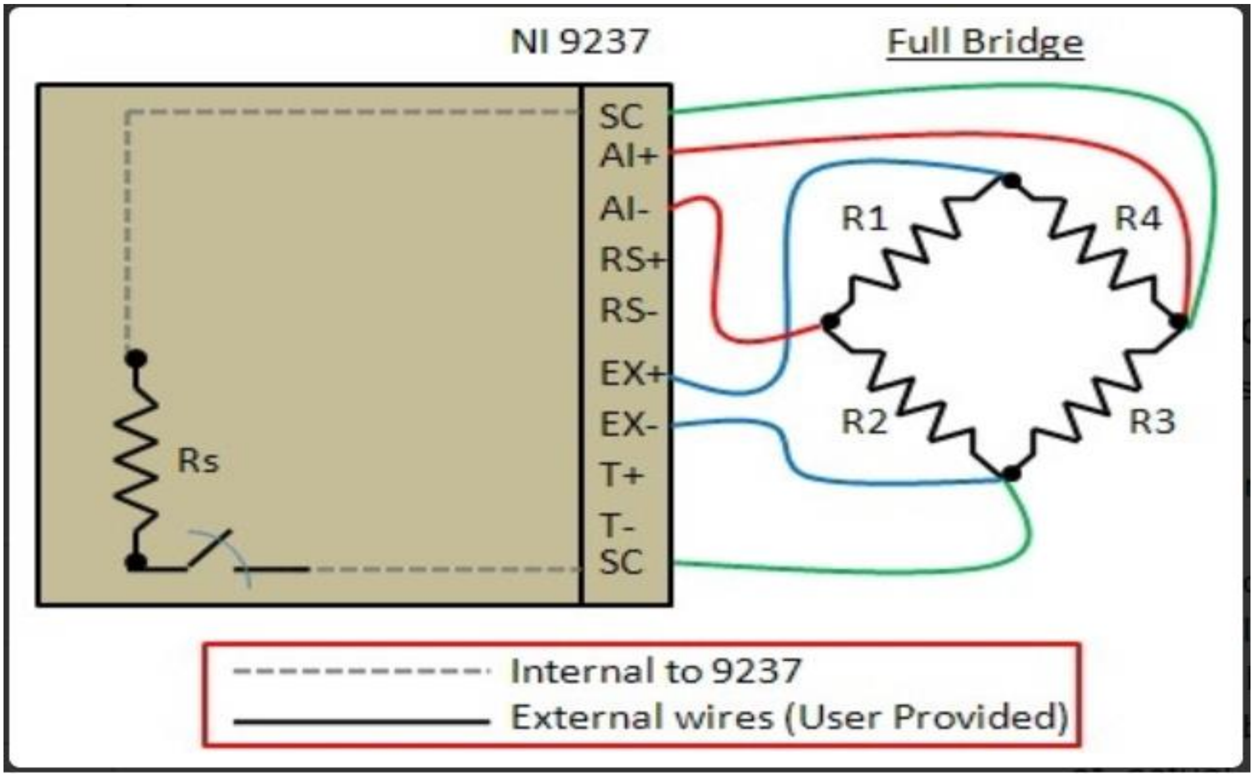
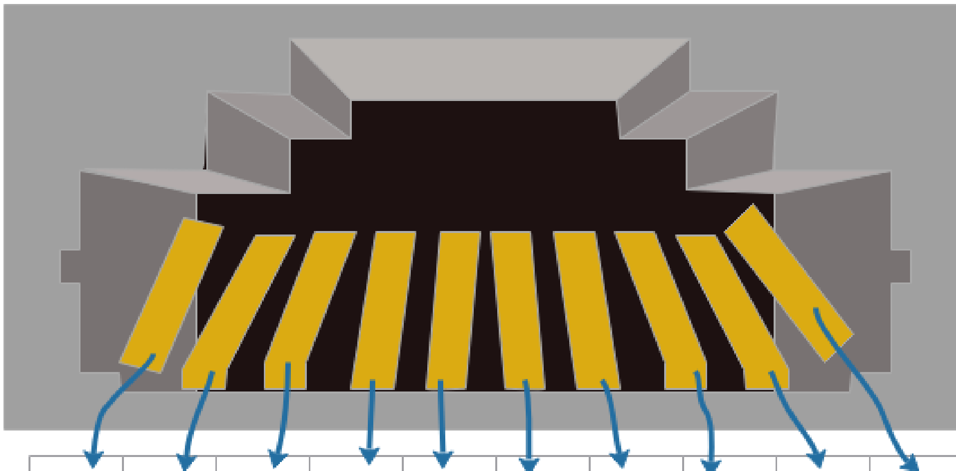


Figure 1: Connection Diagram of Full Bridge Wheatstone with NI9237

Green wire is for shunt calibration.



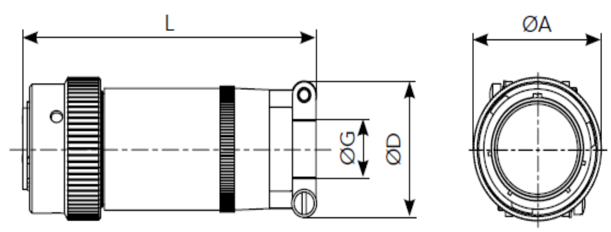
10	9	8	7	6	5	4	3	2	1	Pin No
Light	Light Red	Red	Light Green	Green	Light Brown	Brown	Light Blue	Blue	Dark	Colour
SC	T-	T+	EX-	EX+	RS-	RS+	AI-	AI+	SC	NI9237
-	-	-	B	A	-	-	C	D	-	Strain Guage
-	-	-	B	A	-	-	C	D	-	Accelor meter

Figure 2: RJ 50 Connection Diagram

Plug with straight sealing gland and cable clamp backshells

Cross reference

06 JC	MS 3116 J



Shell size	Part numbers		L max		A max	D max	G max	
	solder contacts	crimp contacts	solder	crimp			min	max
10	851 06 JC 10 .. P/S . 50..	-	57.68	-	21.80	21.50	5.94	6.76

Figure 3: MIL DTL 26483 MS 3116J Receptacle Used

3.3.4 National Instruments Data Acquisition Hardware Chassis NI cDAQ-9172

The NI cDAQ-9172 is an eight-slot USB chassis designed for use with C Series I/O modules. The NI cDAQ-9172 chassis is capable of measuring a broad range of analog and digital I/O signals and sensors using a Hi-Speed USB 2.0 interface. cDAQ chassis and controllers control the timing, synchronization, and data transfer between up to 8 C Series I/O modules and an external or integrated computer. A single NI cDAQ chassis or controller can manage multiple timing engines to run up to seven separate hardware-timed I/O tasks at different sample rates in the same system. Some Specifications are:

a. Analog Input
b. Input FIFO size: 2,047 samples
c. Sample rate
d. Maximum Sample rate: 3.2 MS/s (multi-channel, aggregate)
e. Minimum Sample rate: 0 S/s
f. Timing accuracy: 50 ppm of sample rate
g. Timing resolution: 50 ns
h. Number of channels supported: Determined by the C Series I/O modules
i. Power Requirements
j. Input voltage range: 11 V to 30 V
k. Maximum required input power: 15 W
l. Power input connector: DC input jack with locking, threaded ring 0.8 in. (2 mm) center pin
m. Power input mating connector: Switch craft S760K
n. Bus Interface
o. USB specification: USB 2.0 Hi-Speed Power from USB
p. 4.10 to 5.25 V: 500 µA maximum
q. High-performance data streams: 4
r. Types available: Analog input, analog output, digital input, digital output, counter/timer input
s. Physical Characteristics
    i. Chassis weight (unloaded): Approximately 840 g (1 lb. 13 oz.)
    ii. Chassis dimensions (unloaded): 10.0 in. × 3.5 in. × 2.3 in.

3.3.5 National Instruments C Series Strain/Bridge Input Module NI-9172 Specifications

It is 50 KS/s/channel, Bridge Analog Input, 4-Channel National Instruments C Series Strain/Bridge Input Module. The NI 9172 includes all the signal conditioning required to power and measure up to four bridge-based sensors simultaneously. The module provides strain or load measurements with zero inter channel phase delay. It also has 60 VDC isolation and 1,000 VRMS transient isolation, providing high common mode noise rejection and increased safety. You can program the NI 9172 for use with half-bridge and full-bridge sensors with built-in excitation. The four RJ50 jacks provide direct connectivity to most torque or load cells and offer custom cable solutions with minimal tools.

3.4 Development of Software

The idea was kept very simple that only energy ratios were required at every blow count. Thus the initial development was started using Microsoft Visual Studio 2012. Guidelines were taken from the National Instruments resources available on the internet for .NET initiative of languages. Microsoft Visual Studio 2012 was selected as the programming language because it was part of the course we were offered on the fundamentals of computer programming by MCE.

C# Programming Language was used as it was a multi-paradigm and general purpose object oriented programming language offering a simple typo environment. Our data acquisition device was acquired from National Instruments. The organization offered good manuals for integrating their device to .NET framework. In addition to Microsoft Visual Studio 2012, Measurement Studio 2015 was utilized as it is developed by National Instruments and supports all National Instruments DAQ (Data Acquisition) devices.

Initially the interface designed was having the capability to get input from the user regarding the Grid Reference of the borehole, depth of testing, unit of measurements and data sources. The output was the waveforms of the Accelerometers and Strain transducers and the energy ratio at each depth. Acceleration from the accelerometers is integrated to get the values of velocity. The software was named as SPT Analyzer. Instrumented rod was fixed on top of SPT rods, below the guide rod over which hammer strikes.

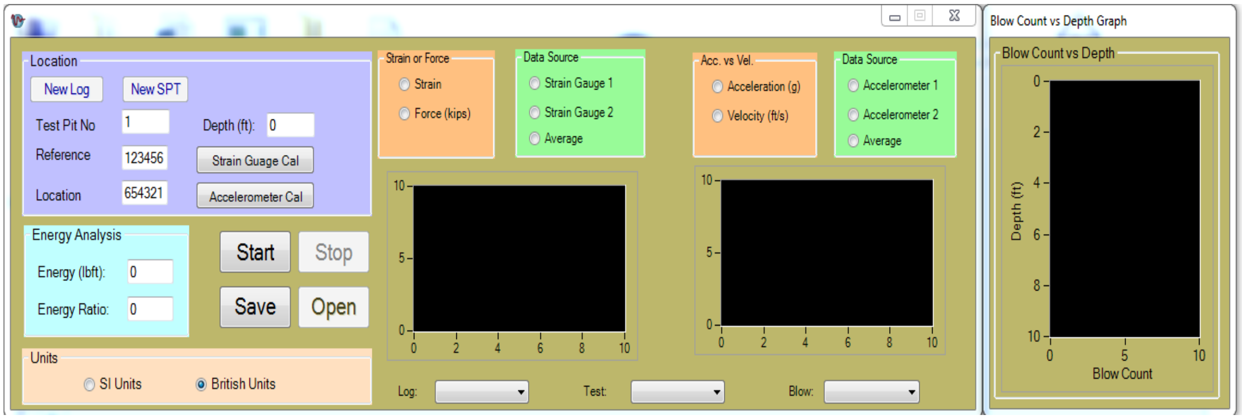


Figure 4: SPT Analysis Tool (SAT), build in Microsoft Visual Studio 2012

The software had the capability to give the very basic of data, which was generally already averaged values. The software was decommissioned due to the following reasons.

a. More time was required to make the software more user friendly.

b. The software required a lot of coding for a very little change in the interface.

c. Error handling was not easy.

d. Debugging a written code is very difficult as it was over 10,000 lines.

Thus, it was felt that for a better user friendly interface, we should shift our coding on a different software altogether i.e. Laboratory Virtual Instrument Engineering Workbench, LabVIEW 2017, which is a system-design development and control environment for visual programming developed by National Instruments.

LabVIEW, using a graphical programming paradigm, gives a lot of flexibility in terms of interface programming and coding with a view to economize time, simplicity and user friendly interface. LabVIEW was used afterwards to create a software that was able to collect data from DAQ, Process it, Perform Signal Modulation, Perform Mathematical operations and Display results.

Robertson et al. (1992) was the first to use the computers for the said purpose. Thus the software developed had two parts or namely modules. First module is named as SPT Energy Measurement and Analysis Tool, SEMAT and the other Acquired Data Analysis Module, ADAM.

SEMAT, is a software which acquires data, signal process it, perform mathematical operations, display acquired and processed data, display final calculations, save all the data and report generation.

ADAM, being the separate software which can be used to read the raw acquired data from SEMAT or PDA (Pile Driver Analyzer), process it, give the output results and give the ability to analyze the data.

Both the software's developed are kept a synch in terms of user interface thus helping in ease of operation. It is designed with a view to meet the available standards and specifications of commercially available systems.

3.4.1 SEMAT (Standard Penetration Test Energy Measurement and Analysis Tool)

SEMAT is an indigenous effort, which acquires, process, display and save data continuously. Following are some features of the application:

a. User Friendly

The interface designed is user friendly and all the commands are readily available on a single click. Scrolling through the tabs is easily and sequenced, thus help a layman understand what is going on. The buttons are like machine buttons thus very basic computer proficiency is required to operate the system.

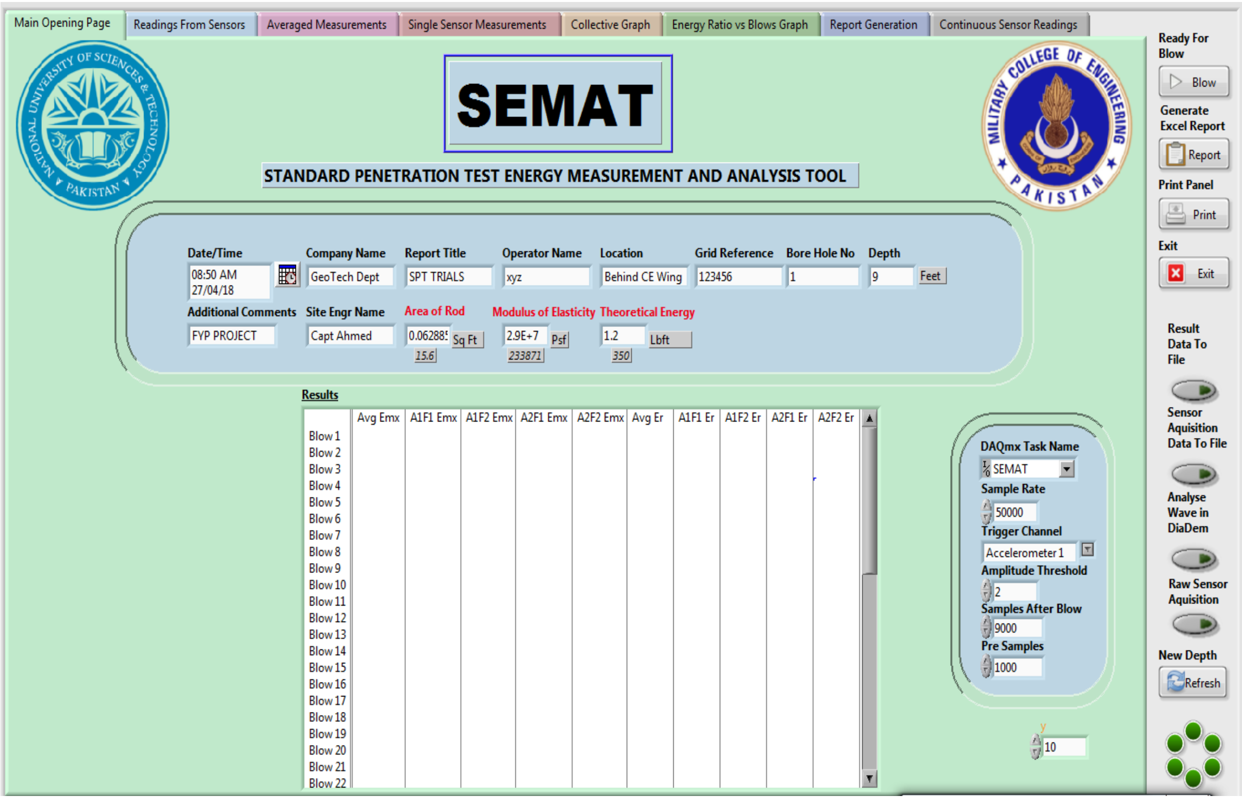


Table 3: SEMAT Interface

b. Rugged and Tough

SEMAT is installed in a Panasonic Toughbook which can be readily used in field with a battery backup of 8 hours. Thus this provide the system an advanced field operability.

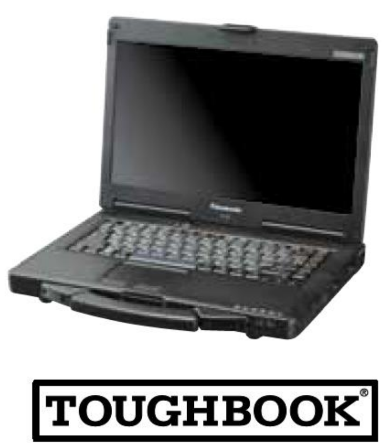


Table 4: Tough Book

c. **Touch Operated for ease of use**

The software is developed and installed in a system capable of operating using touch system, thus the functionality of operation by touch is also added for adding more user adaption.

d. **Automatic Offset Nulling of Sensors**

Sensors after every blow may develop some offsets and require offset calibration. SEMAT automatically detects the offsets and apply the required corrections.

e. **Automatic Trigger control mechanism with customizable parameters**

Trigger channel can be set with customizable values thus enabling it to measure values which can be very less.

f. **Rate of Reading and Number of Samples**

Number of samples or refresh rate or rate of acquisition of data can be modified and number of samples which need to be acquired after the trigger and before the trigger can be modified manually as well.

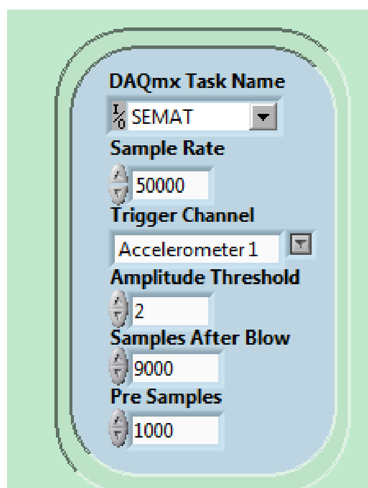


Table 5:Rate of Reading/Sample Rate

g. **Customizable Data saving**

All data that is acquired and the processed data and calculation can be saved into separate files for further viewing and analysis in ADAM. Customizability comes in the form of the options to save the data whether it's the continuous spectrum, whether the velocity or acceleration, whether the processed data and any other format.

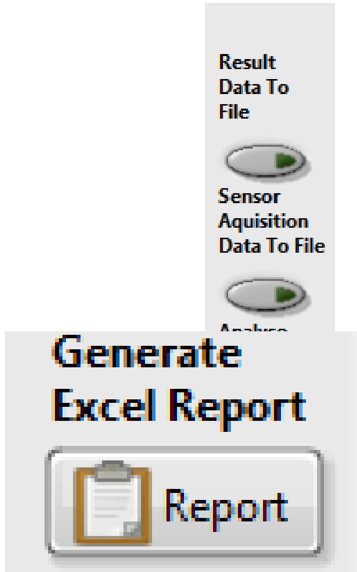
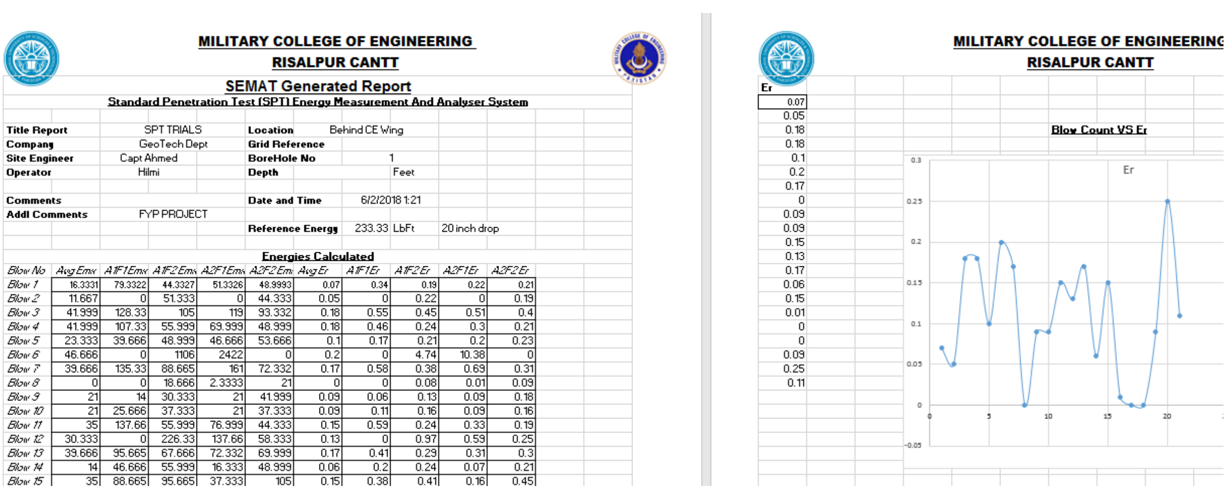


Table 6:Switches for saving Data

h. Report Generation

Report in Excel Format can be generated with a single click, which displays the site information, number of blows and their respected energies acquired from averaged values and the sensor combination values and Energy Ratio vs blow count graph.



MILITARY COLLEGE OF ENGINEERING
RISALPUR CANTT
SEMAT Generated Report
Standard Penetration Test (SPT) Energy Measurement And Analyser System

Title Report	SPT TRIALS	Location	Behind CE Wing
Company	GeoTech Dept	Grid Reference	
Site Engineer	Capt Ahmed	BoreHole No	1
Operator	Hilmi	Depth	Feet
Comments		Date and Time	6/2/2018 1:21
Addl Comments	FYP PROJECT		
		Reference Energy	233.33 LbFt 20 inch drop

Energies Calculated

Blow No	Avg Emx	A1F1Emx	A1F2Emx	A2F1Emx	A2F2Em	Avg Er	A1F1Er	A1F2Er	A2F1Er	A2F2Er
Blow 1	16.3331	79.3322	44.3327	51.3326	48.9993	0.07	0.34	0.19	0.22	0.21
Blow 2	11.667	0	51.333	0	44.333	0.05	0	0.22	0	0.19
Blow 3	41.999	128.33	105	119	93.332	0.18	0.55	0.45	0.51	0.4
Blow 4	41.999	107.33	55.999	69.999	48.999	0.18	0.46	0.24	0.3	0.21
Blow 5	23.333	39.666	48.999	46.666	53.666	0.1	0.17	0.21	0.2	0.23
Blow 6	46.666	0	1106	2422	0	0.2	0	4.74	10.38	0
Blow 7	39.666	135.33	88.665	161	72.332	0.17	0.58	0.38	0.69	0.31
Blow 8	0	0	18.666	2.3333	21	0	0	0.08	0.01	0.09
Blow 9	21	14	30.333	21	41.999	0.09	0.06	0.13	0.09	0.18
Blow 10	21	25.666	37.333	21	37.333	0.09	0.11	0.16	0.09	0.16
Blow 11	35	137.66	55.999	76.999	44.333	0.15	0.59	0.24	0.33	0.19
Blow 12	30.333	0	226.33	137.66	58.333	0.13	0	0.97	0.59	0.25
Blow 13	39.666	95.665	67.666	72.332	69.999	0.17	0.41	0.29	0.31	0.3
Blow 14	14	46.666	55.999	16.333	48.999	0.06	0.2	0.24	0.07	0.21
Blow 15	35	88.665	95.665	37.333	105	0.15	0.38	0.41	0.16	0.45

MILITARY COLLEGE OF ENGINEERING
RISALPUR CANTT

Er
0.07
0.05
0.18
0.18
0.1
0.2
0.17
0
0.09
0.09
0.15
0.13
0.17
0.06
0.15
0.01
0
0
0.09
0.25
0.11

Table 7: Report Generation

i. Analysis of Data in National Instruments DiaDEM software

DiaDEM is a software offered by National Instruments which is a very powerful tool doing any post analysis of the acquired data.

Figure 5: DIAdem LOGO

j. **Continuous Reading from Sensors and display**

Readings from the sensor can be continuously displayed and recorded for any off the system analysis and process. This also indicate the offset and nulling factor of the sensors attached.

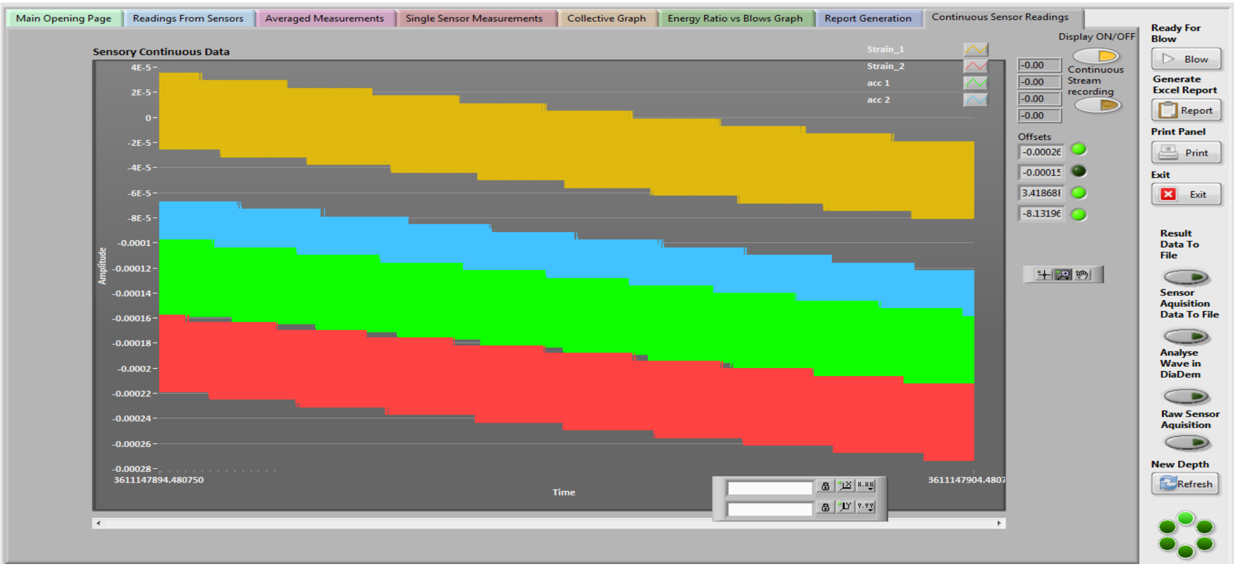


Figure 6: Continuous Data Reading Tab

k. **Different tabs to show all the calculations performed on the signals**

Different Colorful tabs help the operator to continuously monitor the mathematical processes and the minute details of the calculations. This helps in verifying of the data for its validity.

l. Collective graph of Blow counts vs Er

A separate tab is designed to plot the Graph of number of the blows at X axis and the corresponding Energy ratios at y axis. This helps in giving the trend of blows in form of graph which give a rough idea of the SPT values deviation.

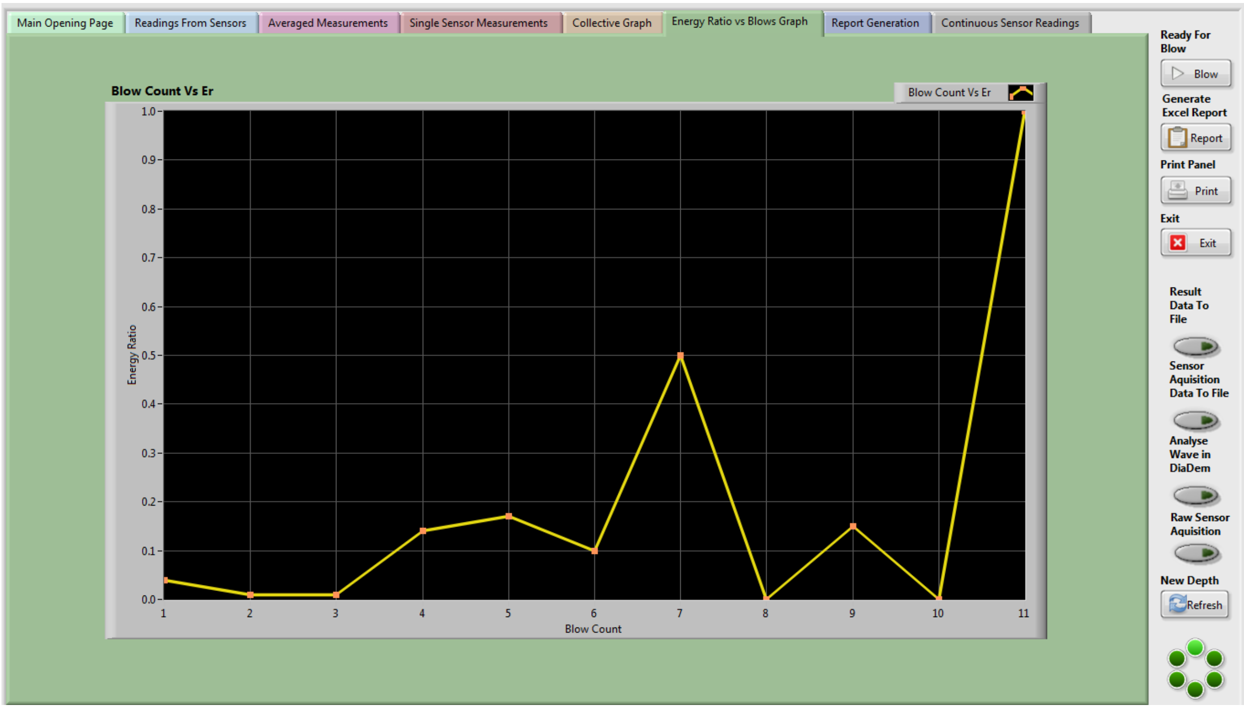


Table 8: ER vs Blow Count

m. Onscreen option of printing the screen

An onscreen button for printing the screen, helps directly printing the said screen. It is most useful when used in context with the report generation tab, which can produce an onsite SEMAT generated printed report.

n. Report Generation Tab.

Onscreen print can be used to print the report directly from SEMAT. This helps in on site print of report possible.

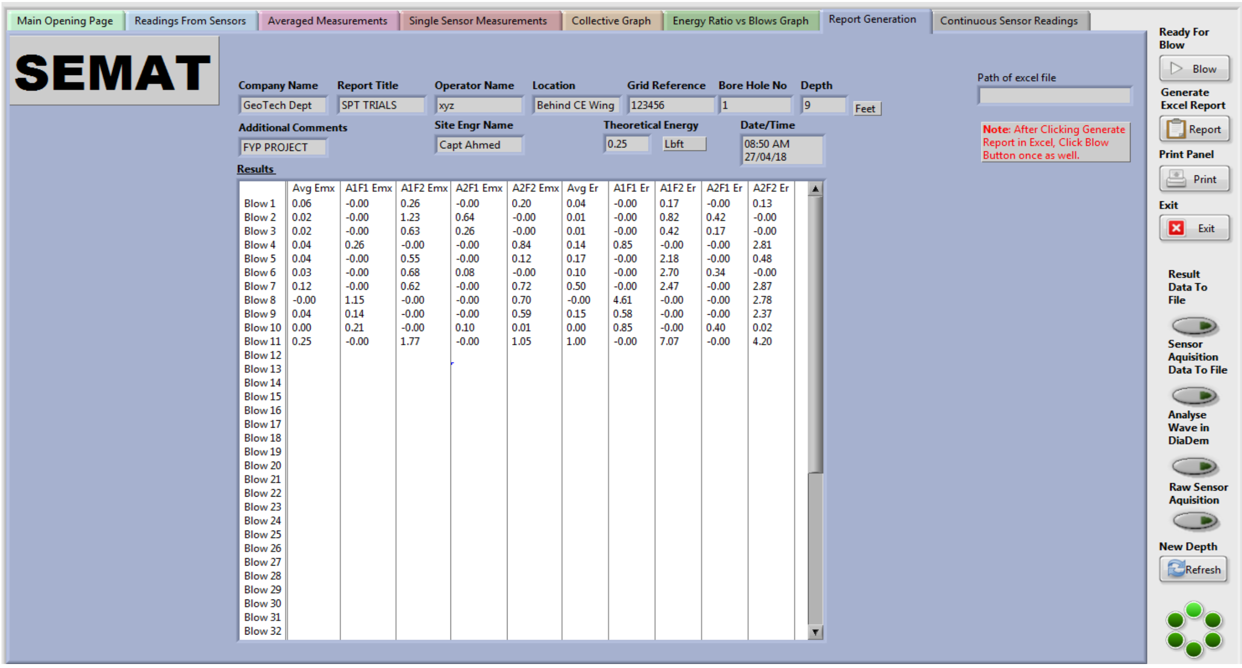


Table 9: Print Tab

o. All data in TDM format which are MS Excel Readable

The TDM format is a standard LabVIEW format which saves the data in tabular format with the timestamp attached to it. This helps in archiving of the data for use of post processing the data, or any future reference.

p. Option to Export any Graph

Any Graph which is seen in the software can be exported in to 4 different ways

i. DiaDEM Analysis
ii. Excel Spreadsheet
iii. Simplified Image
iv. Clipboard

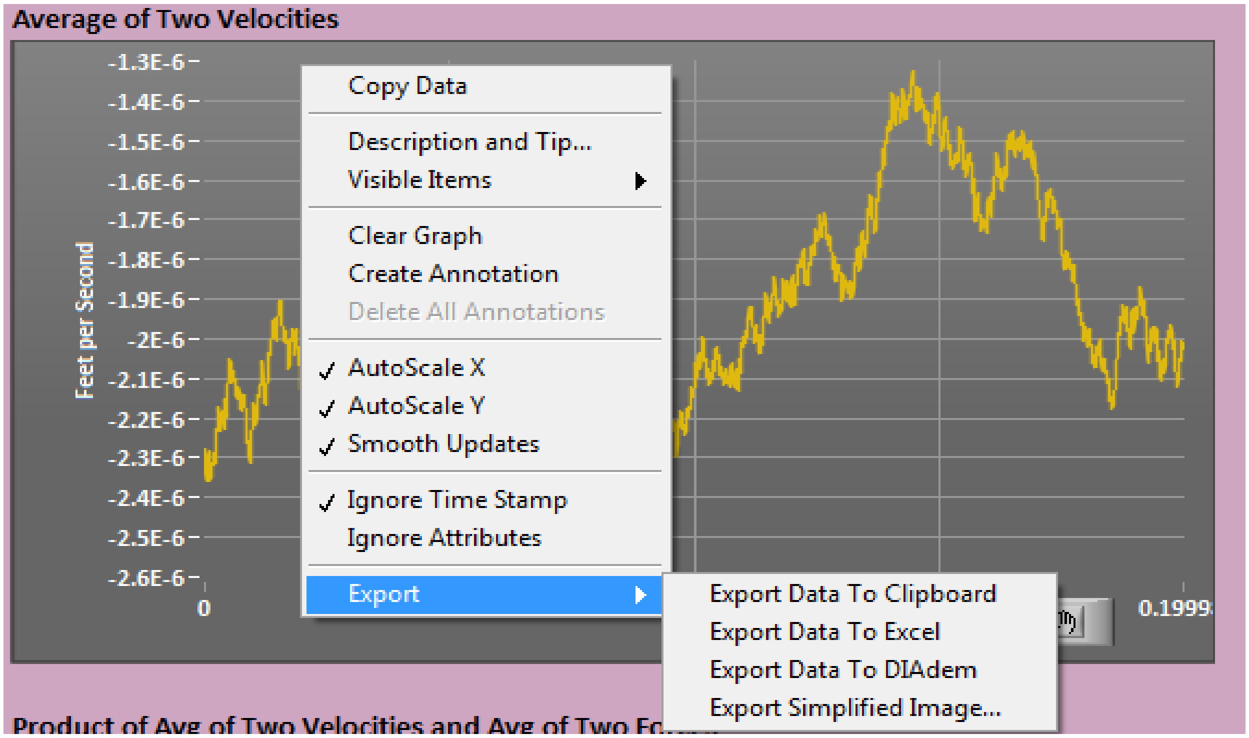


Figure 7: Exportability of Graphs

q. User Customizable Graphs

User has the capability to zoom in or zoom out graph, analyze specific part of the graph and measure values directly from the graph.

3.4.2 ADAM Acquired Data Analysis Module

SEMAT continuously acquires, process and saves data in field, which can be viewed there and then. But to view the previous data in field would be a lot of time consuming and would result in loss of precious time. Thus ADAM was developed with a view to analyze and post process data acquired through SEMAT. Some salient features of ADAM are:

a. User Friendly

The need to keep the software easy to use and long lasting, the best way is to keep the software user friendly and by using very less software based abbreviations. It consists of almost similar tab control as of SEMAT.

b. Can Read Data Already Acquired from PDA or Any Other Source

PDA, Pile Driving Analyzer is very costly tool, which is used internationally for pile analysis, but it can also be used to check SPT Energy. The data acquired by PDA sensors can be used to measure the energy using ADAM.

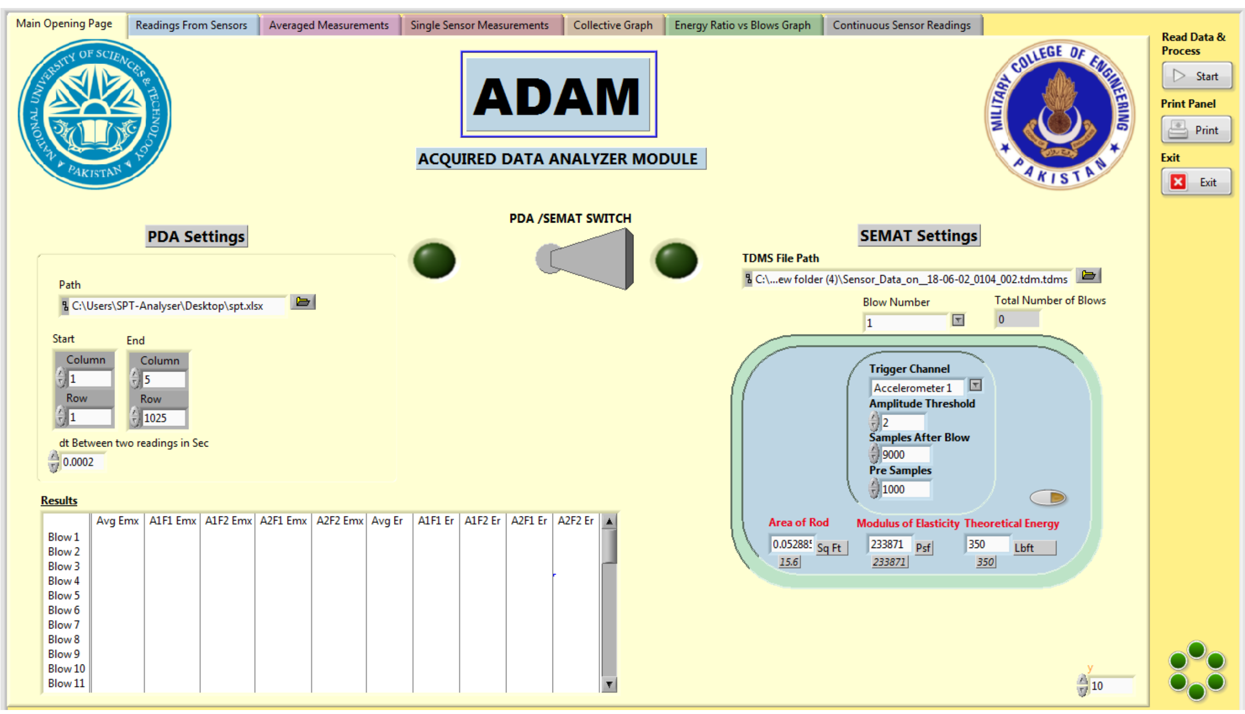


Table 10: Acquired Data Analysis Module (ADAM) Interface

c. Can read all data saved in TDMS format

TDMS, is a format which can be read in MS Excel and can be utilized to save loads of data, which are required for future analysis.

d. Similar User Experience as of SEMAT

As it is a sister application of SEMAT, thus effort has been made to keep the interface as common as possible, enabling the user a trouble free easy to use environment.

3.5 Methods of Energy Measurement

As mentioned earlier there are two common methods for the calculation of energy but we are using FV (Force Velocity) method only as this is advanced than F2 method. We measure transfer energy as:

$FV = \int F(t)V(t)dt$

Here: F is the force at time t

And: V is the velocity at time t

Integration starts at the time of impact (time when energy transfer start) and stops at the time when transferred energy to the rod reaches maximum value. According to Aboumatar & Goble 1997 theoretically this method does not require any correction factors. Changes in cross-sectional area does not affect this method, researchers believe that this method is accurate one. We are using the same method in our project. It integrates the product of force and velocity with respect to time. Then we get actual energy transferred. Theoretical potential energy is given as input to the system. System gives us the ratio between actual energy to the theoretical energy.

Chapter 4

FIELD TESTING AND ANALYSIS

4.1 Introduction

Before going directly for the field tests, we carried out initial model study in research room SAGE and MCE Geotechnical laboratory. In this preliminary phase we carried out numerous trials for the development of SEMAT using manual sledgehammer. After carrying out successful laboratory trials we proceeded for field tests. For this, suitable test site was required to be selected.

4.2 Test Site

We were required to have site which is preferably sandy soil. After obtaining information from local area contractors and laboratory staff we selected the site behind Civil Engineering Wing MCE. As shown in figure.

Figure 3: Site location

4.3 Site Preparation and Equipment Used

Since we had to calibrate the hammer energy of SPT so we were required to have known value of Elastic Modulus of below strata from which ENTHRU was to be calculated, hence base concreting (3000 psi) of 3 feet depth was carried out in each hole. Afterwards installation of PVC pipes of 4-inch diameter was made. To keep those pipes straight in place we have done side concreting as well. To avoid spilling of water and waste etc. pipes are covered atop with pipe caps. Manual SPT procedure was adopted for the test. Major equipment used is as under:

a. Donut Hammer
b. Tripod along with Pulley
c. Extendable pipes for tripod
d. Rope
e. Guide rod
f. SPT rods (3 and 5 feet lengths)
g. Split Spoon Sampler (Standard Liner)

The above mentioned equipment used for the testing purpose was the property of MCE Geotechnical Laboratory. In addition to above standard equipment, instrumented SPT rod along with requisite data acquisition system is also used.

4.4 Procedure adopted

First of all, tripod was erected over each borehole one after the other, its height was adequately provided so as to have the required drop height available for the hammer. After installation of the tripod, hammer (140 lbs.) attached with the rope was pulled through the pulley to varying heights for the boreholes (As height does not have any effect on energy ratio). Hammer is then relieved by the operator enabling the hammer to be dropped with minimum friction resistance. All the efforts need to be made to keep the drop as vertical as possible so as to avoid sliding of hammer which affects the results obtained by the accelerometers and the strain transducers.

4.5 Data Analysis

4.5.1 Data Acquisition

Each blow of hammer strike will result in provision of reasonable readings which are obtained from accelerometers and strain transducers connected through cDAQ to the Tough Book. Data is acquired on SEMAT program (an indigenous effort of the team conducting the tests), where in every blow results in velocity and force waveforms. It was important to evaluate the efficiency of both the accelerometers and strain transducers to be working in synchronization and should give results as per standards. Moreover, it was required to judge any event which affects negatively to the output of the SEMAT program and quality of the results obtained. Undermentioned are few of those events:

a. Bolts get loosened after certain blows.
b. Effect of Inclination of rod. (Inclination of hammer strike towards one side, results in higher sensor value from that side).
c. Sliding of hammer

Tests data attached as Annexure provide the time, blow count, maximum and average velocity, force and displacement in the rod. A good data gives both the velocities and both the forces proportional to each other, thus indicating that all the gauges are working properly. Such data shows fair proportionality of the velocity and the force starting from initial impact till the end after time 2L/c. Similarly, proportionate data is not obtained once malfunctioning of any of the sensors due to either loosening of the bolts of the sensors or sliding of the hammer is encountered.

4.5.2 Exclusion of non-standardized data

Non-standardized results obtained due to either loosening of the bolts, or sliding of the hammer with each successive blow are discarded. Notable differences in sensors readings depicts the malfunctioning in data acquisition.

During the conduct of the field tests it was observed that data which is outlier either larger than the average or too less than the average was discarded. As it is due to poor signal generation by either set of sensors. So such data was not counted in the overall results generation.

4.5.3 Comparison with PDA

Results were compared with the results obtained from Pile Driving Analyzer (PDA) at the same site and these were almost similar to each other. Below are the graphs showing results of PDA data.

First graph shows out of range value for the blow count number 1. But the second graph shows the proportionality of the data.

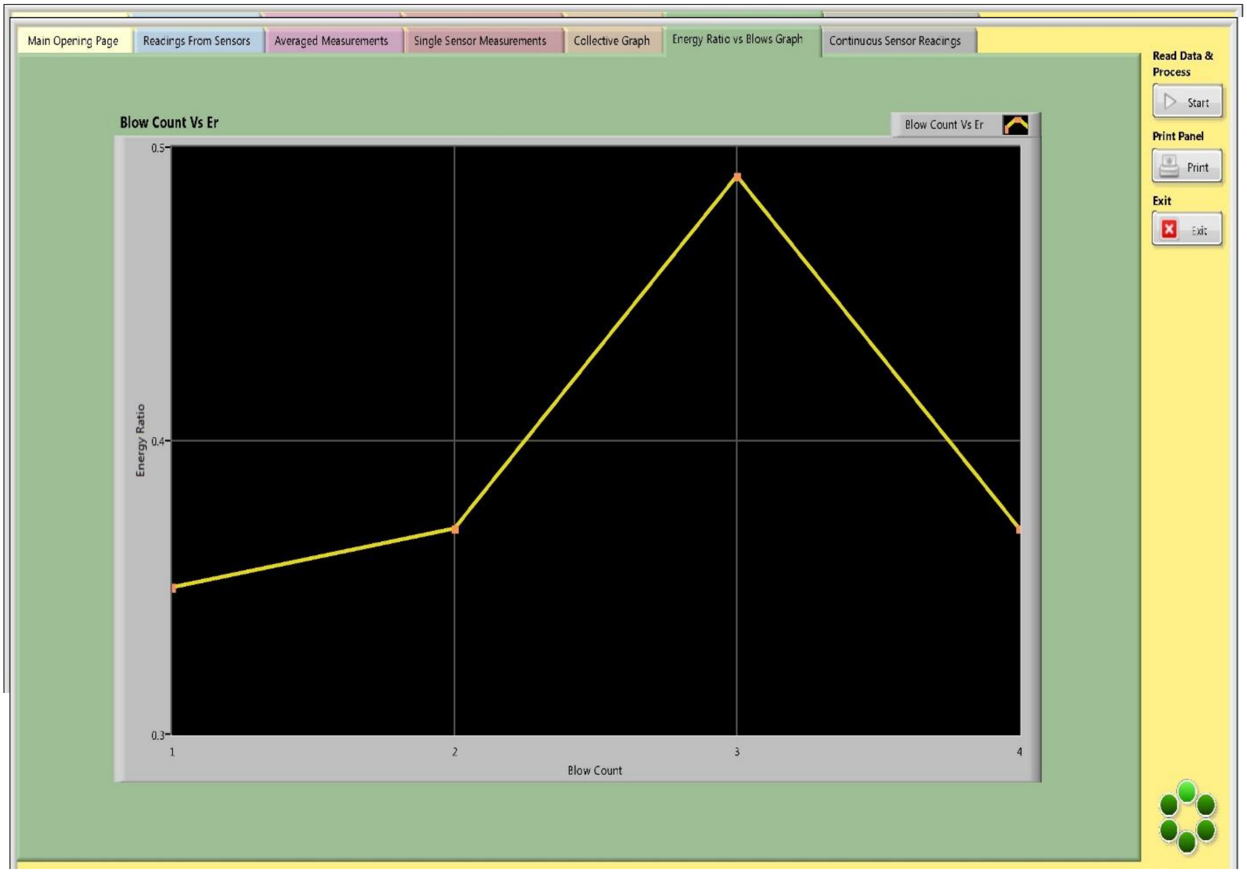


Table 124: Graph 2 showing proportionality of the data

This graph shows the Average Energy Ratio around 38%

Thus the correction factor is

=38*100/60

= 63.33%

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Following are the conclusions based upon the evaluation of hammer energy calibration.

a. Energy ratio measured using SEMAT on MCE geotechnical lab equipment resulted in Energy ratio of 34% (which is 57% reduction factor).

b. After analyzing the results, a FOS 4 to be used on future calculations based on SPT.

c. For reliable bearing capacity, field blows should be multiplied with 60% efficiency.

d. SPT is currently considered to be the most economical and reliable method for obtaining soil strength parameters and sub-surface investigation.

e. Though greater work has been done yet variability is the integral property of the system due to variety of hammer types (Donut, Safety, Automatic & Pin weight), different types of drilling rigs, different types of drill rods, variations in rod diameters and rod lengths, variety in sampling tubes (Split Spoon Sampler, Shelby Tube Sampler) and diversity in energy delivering systems.

f. Energy delivered to the rod is always less than the theoretical energy.

g. SPT N value is not merely consistent to any standardized practice.

h. It was observed during the test that energy ratio increases with the increase in rod length up to 10m.

i. There is an inverse relationship between ENTHRU and N value.

j. Custom made rod threads by local blacksmith have less strength thus contribute towards tilting of the rods.

5.1.1 Address to research questions

Our research was primarily based on few of the research questions which were highlighted in the introduction part, those are being addressed here briefly:

a. Hardware has been developed in the form of instrumented SPT rod with cDAQ and Software solution has been provided in the form of SEMAT which basically is Standard Penetration Test Energy Measurement and

Analysis Tool used directly in the field, and ADAM which is Acquired Data Analyzer Module used for offline data processing.

b. There are numerous causes which add up to hammer energy loss in SPT but main cause as per the test results is Non-verticality and Sliding of Hammer.
c. Average Reduction factor found out during field tests is around 55-65 % which means that hammer energy delivered is around 30-40% against the Normalized 60%.
d. To minimize the losses of hammer energy, it should be carried out on automatic SPT machine and drill rigs.

5.2 Recommendations

5.2.1 Immediate Measures

Although all the corrections of SPT N value are minor except the corrections related to the different types of hammer. To overcome this following is recommended:

a. SEMAT is recommended to be used for Energy calibration on variety of SPT equipment.
b. To cater for the wear and tear of the SPT equipment, energy measurement should be done intermittently.
c. For sensitive buildings use Automatic SPT method instead of manual, since after each blow the alignment of hammer gets disturbed which lead to the sliding of the hammer.
d. A based end Split spoon sampler to be used for the test
e. SEMAT should be tested in the field on different soils to note down the differences in efficiencies
f. It was observed during the test that the difference in hammer drop height does not affect the ratio of energy delivered to the system. So hammer energy can be calibrated on varying heights.

5.2.2 Directions for Future Research

a. One of the long term measures could be to standardize the hammer systems, so that each hammer type should provide 60% efficiency. This can be done by either modifying the weight of the hammers or the strokes.

b. Energy calibration should be carried out on different type of SPT equipment being used in Pakistan by different companies in the field.

c. This calibration should be carried out on automatic SPT machines as well as drill rigs and results be compared.

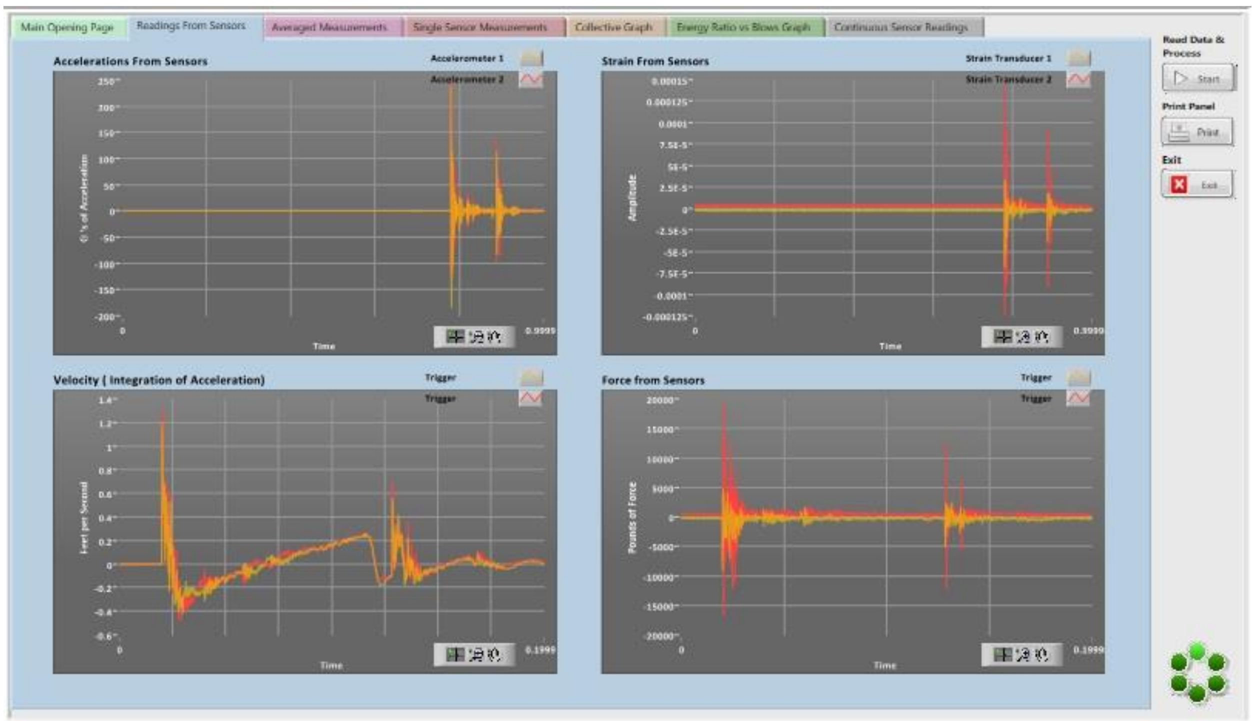
d. In future, calibration should be done using foiled strain gauges and results be compared with the current system having strain transducers.

e. Since the actual energy required to drive the sampler is the energy available just above the sampler and not below the anvil, so another instrumented assembly should be developed that could measure the energy just above the sampler when borehole depth is more than 5 meters.

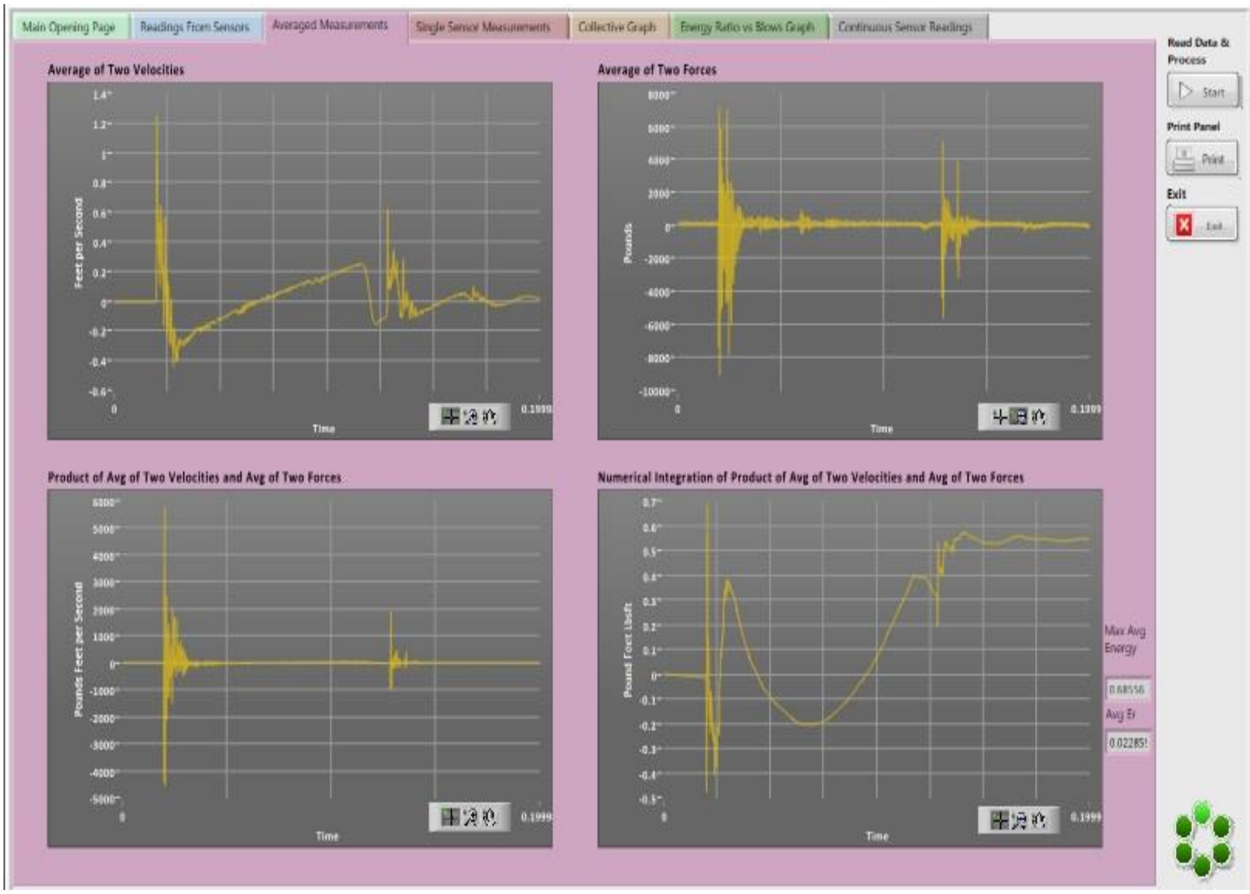
Annexures

Annex A

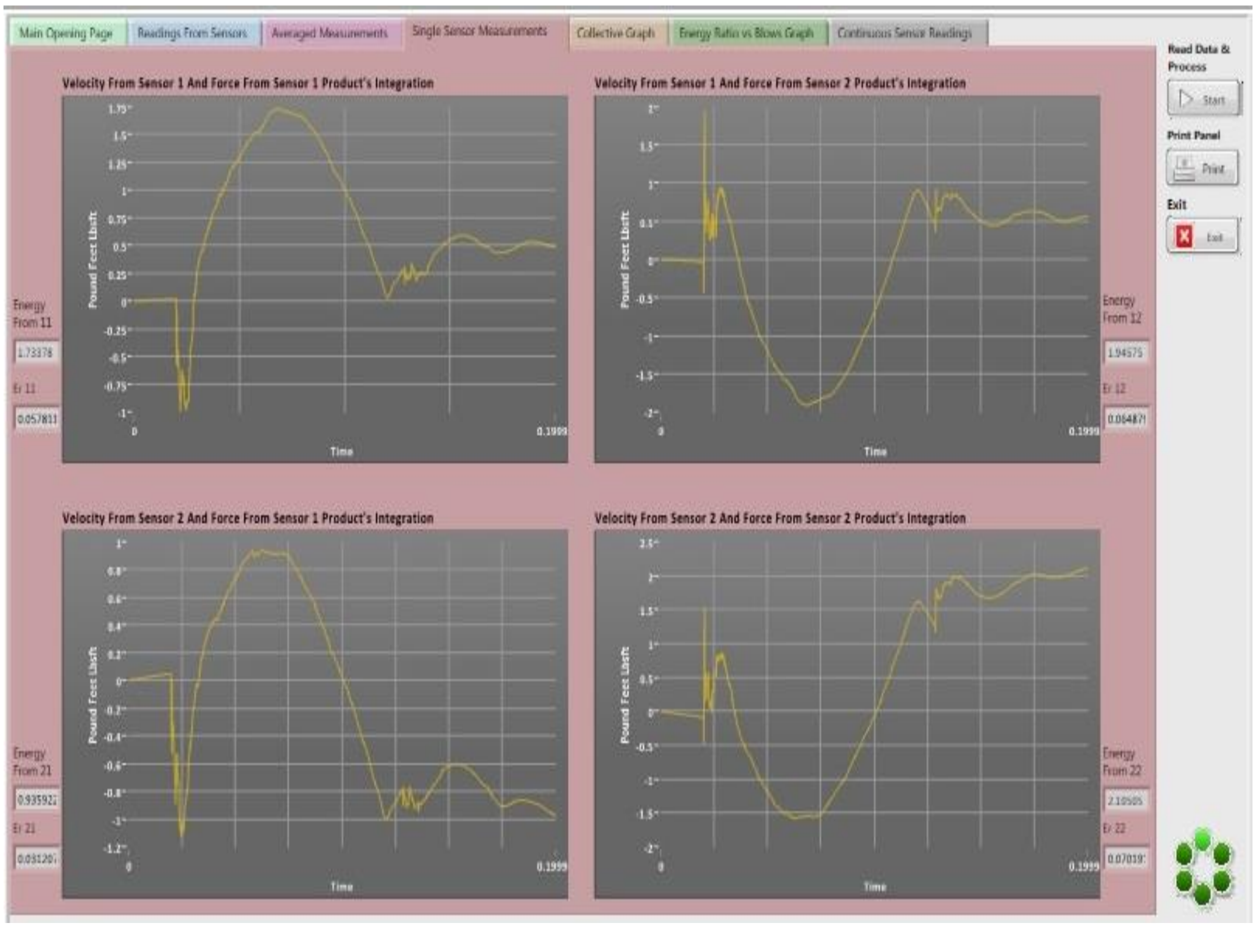
Blow count number 1. View of first tab



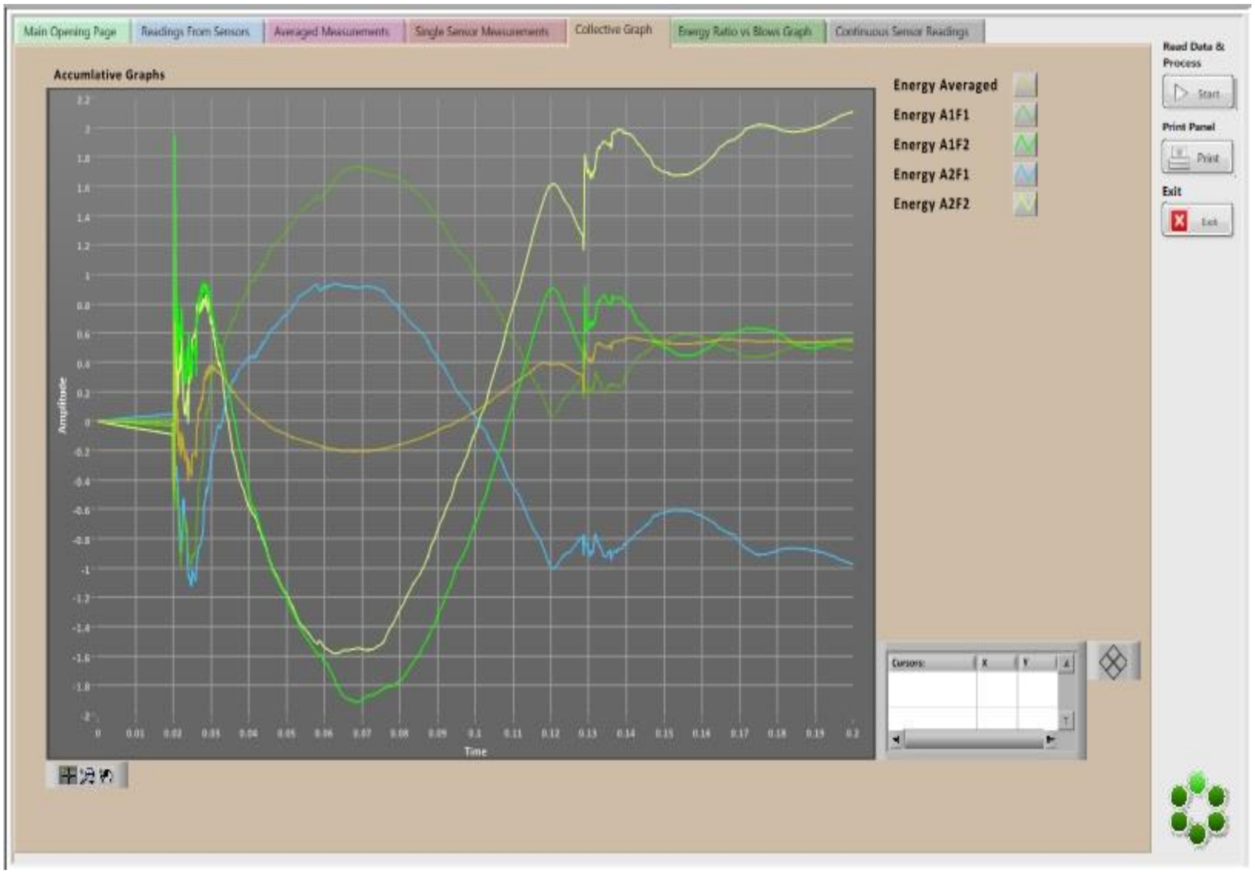
Blow count number 1. View of second tab



Blow count number 1. View of third tab



Blow count number 1. View of fourth tab



References

1. Arce, C. M., Torres, F. L., and Vercelli, H. J. (1971) "Compared Experiences with the SPT," Proceedings of the 4th Pan American Conference on Soil Mechanics and Foundation Engineering, San Juan, Puerto Rico, Vol. II, pp. 95-104.
2. Fletcher, G. F. A, (1965) "Standard Penetration Test: Its Uses and Abuses", Journal of the Soil Mechanics and Foundation Engineering, Vol. 91, No. SM4, pp. 67-75.
3. Kovacs, W. D., Salomone, L. A., & Yokel, F. Y. (1981). Energy measurement in the standard penetration test. *NASA STI/Recon Technical Report N*, *82*.
4. Sherif, A. M., & Radding, R. (2001). Standard Penetration Test (SPT) Correction. University of Maryland, Department of Civil and Environmental Engineering.
5. Sy, A., & Campanella, R. G. (1991). An alternative method of measuring SPT energy.
6. Schmertmann, J. H. (1979) "Statics of SPT," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT5, May, pp. 655-670.
7. Schmertmann, J. H., and Palacios, A. (1979) "Energy Dynamics of SPT," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT8, pp. 909-926.
8. Lamb, R. (1997, February). SPT Energy Measurements with the PDA. In 45 th Annual Geotechnical Engineering Conference at the University of Minnesota.
9. Davidson, J. L., Maultsby, J. P., & Spoor, K. B. (1999). Standard penetration test energy calibrations.