STANDARD PENETRATION TEST: A COMPARATIVE ANALYSIS BETWEEN AUTO TRIP & MANUAL RIG SYSTEMS

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A Thesis submitted to the Department of Civil Engineering, Daffodil International University
in partial fulfillment of the requirements for the Degree of
Bachelor of Science in Civil Engineering

Department of Civil Engineering
Faculty of Engineering
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The thesis titled **"Standard Penetration Test: A Comparative Analysis Between Auto Trip & Manual Rig Systems"** submitted by Md. Mizanur Rahman (Student ID: 192-47-1022), Menhazuddin Rasal (Student ID: 172-47-504), Session: Summer 2019 & Summer 2017 been accepted as satisfactory in partial fulfillment of the requirements for the degree of Bachelor of Science (B.Sc.) in Civil Engineering on January 16, 2023.

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The thesis titled "Standard Penetration Test: A Comparative Analysis Between Auto Trip & Manual Rig Systems" was completed under the supervision and guidance of Mr. Mohammad Mominul Hoque, Assistant Professor, Department of Civil Engineering, Daffodil International University, Dhaka, Bangladesh.

The thesis has been accepted as partial fulfillment of the requirements for the degree of Bachelor of Science in Civil Engineering. The centerpiece, to the greatest of our knowledge, does not contain any previously published or written works by others, unless appropriate citation is provided in the centerpiece proper. It is hereby declared that this dissertation or any part of it has not been submitted elsewhere for the award of any degree or diploma.

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DEDICATION

Dedicated

To

Our Parents

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ABSTRACT

The Standard Penetration Test (SPT) is one of the widely used tests for subsurface exploration in Bangladesh. Generally two types of SPT rig systems are used, namely manually operated and auto trip systems. Most of the SPT is performed by a manually operated SPT rig system where keeping the standard free-falling height of the SPT hammer is quite difficult. In addition to that, nonstandard equipment and operational procedure, unskilled rig operators, and absence of regulatory bodies, the quality of the SPT data is unreliable in Bangladesh. In this study four manually operated and four auto trip SPT rig systems were examined at eight different sites. Then both systems were compared with respect to the ASTM standard in terms of hammer weight, dimensions of the split-spoon sampler, free-falling height of hammer, and energy efficiency. It was found that an auto trip hammer weight is 3.31 lb and a manually operated hammer is 7.4 lb less than the standard weight while the remaining six hammers weigh within the standard range. The length of the split barrel of all sites were found within the standard range. The inner diameter of a split barrel was found 5.27 mm less and outer diameter of three split barrels were found 1.62 mm, 1.82 mm, and 1.45 mm larger than the standard diameter. The thickness of a driving shoe was found 1 mm less and three driving shoes were found 0.49 mm, 0.62 mm, and 1.29 mm greater than the standard thickness respectively. The inner and outer diameter of five and six driving shoes were found greater than the standard diameter. The inner and outer surface of the split spoon samplers were found rusty in different digress. In case of manually operated rig system total 1252 hammer blows were recorded where only 468 blows were released from the standard free-falling height of 30 inch, which is 37.4% of total blows and 784 blows were released from a height either greater or lower than the standard free-falling height of 30 inch, which is 62.6% of total blows. In case of auto trip rig systems total 643 hammer blows were recorded and the standard free-falling height of 30 inches were maintained. It was found that the hammer energy transferred to the anvil for manually operated and auto trip rig systems varies between 99.4% to 99.5% and 89.4% to 113.7% respectively. The nonstandard practice is higher in case of manually operated rig systems as compared to the auto trip systems. Nonstandard practices are responsible for over/under estimation of soil's strength. Due to the unreliability of the SPT data, the projects are often over designed, hence uneconomic.

LIST OF NOTATIONS AND ABBAREVIATIONS

List of Notations

C_B	Borehole diameter correction
C_S	Sampler correction
C_R	Rod length correction
D	Diameter
D(hollow)	Diameter of hollow section
E_H	Hammer efficiency
E_r	Energy efficiency
N	Measured SPT N-value in field
N_{60}	Corrected SPT N-value for field procedures

List Abbreviations

ASTM	American Society for Testing of Materials
BH	Borehole
DCPT	Dynamic Cone Penetration Test
SPT	Standard Penetration Test

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CHAPTER ONE
INTRODUCTION

1.1 General

The standard penetration test is one of the in-situ testing techniques (SPT). SPT is used to determine the soil type, stratigraphy, and relative strength. SPT, which was created in the USA, is a tried-and-true technique for examining soil characteristics including bearing capacity and liquefaction. Since there are several test types in use across the world, standardization is crucial to make it easier to compare the findings of various investigations, even when they are conducted at the same location.

Standard penetration tests (SPT), utilizing a manually operated donut hammer weighing 140 lb were carried out in the boreholes at 5 ft intervals. In order to guarantee a free-falling height of 30 inch, an auto trip gear was employed in the hammer drop mechanism. SPT often came to an end after a limit of 50 blows for any penetration that did not exceed 18 inch. The typical split spoon sampler has a ball valve on top to allow air or water to escape when driving and to help retain sample while drawing it out. The sampler was placed into the borehole after being attached to the necessary length of BW size drill string. Three sets of blows are recorded: the number of blows needed to drive the sampler, which is 18 inches long, and the number of blows needed to penetration it, which is 6 inches long. The total of the final two sets of strikes needed to penetrate 12 inches (6 inch + 6 inch) is the SPT N-value. The initial set of blows for a 6 inch penetration were counted as seating blows; however, this amount is disregarded for calculating N-values. A record was made of the equivalent penetration resistance.

The test may be completed promptly. The test technique is somewhat easy to carry out. The identification of a soil type can be done using collected soil samples. It is possible to determine the soil's compressibility and relative strength index using SPT data. In Bangladesh, the maximum standard penetration test (SPT) is performed with a hand-operated hammer and a very small percentage is performed with auto tripper hammer. SPT-N values are problematic due to non-standard manual testing in Bangladesh. Test results are also affected due to lack of instruction, professional training of operators, lack of expertise, lack of regulatory authority, equipment maintenance, etc. Due to these influencing factors, the recorded SPT-N values and the estimated soil properties deviate from the actual. Non-standard practices can also lead to overestimation or underestimation of soil strength, resulting in unsafe or uneconomical foundation design. The open ended sampler is replaced by a cone end in rocky soil and gravelly soil. Investigations have discovered that N- values for the two types – in soil with almost the same density are often similar.

The purpose of the thesis is to compare the results of manual and auto hammer penetration tests in Bangladesh. Five different sites' performance is evaluated, and its results are compared to those in ASTM standard methods for standard penetration tests. The weight difference of hammer, split spoon sampler, driving shoes, drilling rod, and values from five separate locations are compared to ASTM standards in this study. A general understanding of soil type is gained. Additionally, to determine the free-falling heights between manual and auto-operated hammers. The kind of soil and the soil's N value may be determined by counting the number of blows from the field and find out its simplicity.

1.2 Thesis Background

The standard penetration test (SPT), created in the late 1920s, is now the most widely used and cost-effective technique for subsurface sample for geotechnical research. The outcome of the test can be significantly impacted by inconsistencies in the testing process itself, such as differences in hammer types and operating factors.

Burmister was the one who initially proposed the idea of energy rectification (1948). He proposed a straightforward input energy adjustment for the driving weight (hammer energy) versus sample diameter ratio. Since then, much study on the energy issue has taken site-specific considerations into account. Unfortunately, there are very few studies on SPT in relation to site variables in Bangladesh.

Bangladesh has many high-rise buildings that have been constructed without any kind of standard penetration test. In addition to this most drill operators in Bangladesh have no professional training to maintain SPT requirements. A 140lb hammer is dropped on an anvil to perform the test, and although the weight of the hammer may change over time due to wear and tear, rust, or repair work, it is rarely measured. 18 inches into the soil with a split-spoon sampler. To penetrate the depth, the free-falling height of the hammer should be 30 inches, but this is quite difficult to control with a manually controlled hammer. Due to excessive use, non-repair and rusting, the inner diameter and driving shoe thickness of split-spoon specimens may change over time, but they are rarely investigated. As a result of which many accidents often occur. If building can be constructed by standard penetration test then such accidents can be avoided. Due to the high limitations, measured SPT-N values may lead to aspersion or excess of penetration resistance. Therefore, it is important to study current SPT practices related to ASTM standards and acknowledge how non-standard practices may affect soil permeability and strength. All critical areas should be highlighted and investigate by structural audits which should also suggest immediate corrective and preventive actions

1.3 Objective of the Study

1. To compare auto trip and manual Standard Penetration Test (SPT) rig systems.
2. To compare both systems in terms of equipment and operational procedure with respect to the ASTM standard.

1.4 Scope of the Study

The principal purpose of this research is to compare the SPT readings from five different sites to the ASTM standard. For proper practice, a variety of codes are used. Therefore, only ASTM standards were applied to in this investigation. In this study, sampling is crucial since it saves time. Samples help to avoid asking the same question to every specific individual. However, choosing a decent sample is really challenging. SPT can be affected by many factors such as inadequate supervision, incorrect drilling procedures, use of non-standard apparatus, dumbbell assembly, incorrect use of weights, free falling height of weights, blow rate, etc.

In this research total five site soil were selected in Dhaka and Rajshahi city to collect the data manual SPT rigs were used for sub-surface exploration of four sites. And auto hammer is used on a site. First the SPT equipment used by the rig operators is closely inspected. The inside diameter of the split-spoon sampler, the thickness of the driving shoes, is measured in millimeters by a Vernier scale. Also the weight of the hammer is estimated by multiplying the actual volume of the hammer by the unit weight of the steel. And the weight of hammer is measured by digital weighing machine. The exact free-falling height of the hammer is measured by high-definition video recording. To establish a free-falling height reference point, the anvil is marked at 3-inch intervals above and below the standard 30-inch free-falling height. Free-falling data were collected from five boreholes spaced five feet apart at depths of 100 ft, 65 ft and 120 ft. We then performed slow motion video recordings to measure the exact free- falling height of each blow.

1.5 Organization of the Thesis

This paper is divided into five chapters, and an overview of each chapter is summarized below to assist the reader.

The first chapter presents an introduction to the topic, background of the thesis, objectives, research scope and organization of the thesis.

The second chapter presents an in-depth literature review on standard penetration test (SPT), specially the standard analysis of equipment, test procedures, the main factors affecting SPT-N values, and the capacity of the device. Critical condition associated with the field practice of standard penetration test (SPT). Also, briefly describe hammer energy, fixes for SPT, and previous research.

Chapter three outline the field investigations. In the first section, the site selection, quality of materials and equipment, and data collection and analysis are described in detail.
The results obtained in this study are presented and compared with the ASTM standard in chapter four. How non-standard practices can affect soil strength predictions are also discussed.

Observations, restrictions, and suggestions for more research pertaining to the scope of this study are all included in chapter five.

CHAPTER TWO
LITERATURE REVIEW

2.1 General

A literature overview of the standard penetration test equipment and operating standards has been presented in this chapter along with a brief description of the SPT. The main influencing factors affecting SPT are discussed. In addition, hammer energy efficiency, correction factors and previous studies were also discussed.

2.2 Description of the Standard Penetration Test (SPT)

In April 1958, the American society for testing and materials (ASTM) committee on soils for engineering purposes published a draft method for penetration testing and split-spoon sampling in accordance with bins, because the information contained in an anthology allows testing bases. In June of that year, ASTM adopted the interim method at its annual meeting for use pending acceptance as a standard.

This test method describes a procedure, commonly known as the standard penetration test (SPT), for driving a split spoon sampler to obtain a representative disturbed soil sample for identification purposes and for measuring against intrusion of the sampling device. Another method [1] is available for driving a split-barrel sampler to take a representative soil sample, but the power efficiency of the hammer is not standardized.

2.3 Apparatus Standard and Test Procedure

Any drilling equipment ensures proper borehole before inserting the sampler and also ensures that penetration is done on undisturbed ground.

2.3.1.1 Drag, Chopping and Fishtail Bits

The bottom discharge bits are not allowed to avoid disturbance of the ground below, only the side discharge bits are allowed. Drill bits, of graders larger than 2.25 inches (57 mm) in diameter and less than 6.5 inches (165 mm) in diameter are permitted in combination with either rotary open hole drilling or casing pipe elevation drilling.

2.3.1.2 Sampling Rods

Flush joint steel drill rods are used to mount split barrel samplers for drive weight representation. The sampling rod shall be a steel rod with an outside diameter of 1.625 inches (41.3 mm) and an inner diameter of 1.125 inches (28.5 mm) and length 10 ft.

Figure 2. 1: Sampling Rod Image Source Site

2.3.1.3 Split-Barrel Sampler

The dimensions of the standard split barrel sampler are shown in Figure 2.1. The sampler has an outside diameter of 2 ± 0.05 inch (50.8 ± 1.3 mm) and inner diameter of 1.5 ± 0.05 inch (38.1 ± 1.3 mm). Length 18.0 ± 30.0 inch (457 to 762 mm) A Ball check and vent must be added with the split barrel sampler.

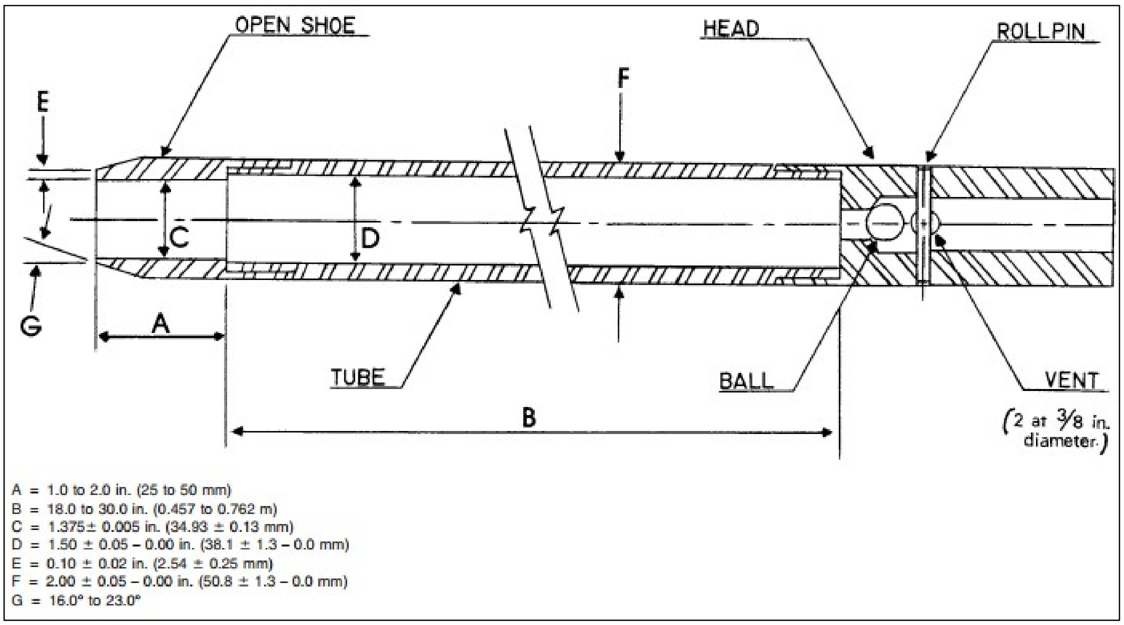

Figure 2. 2: Standard Split Spoon Sampler Image source: [1]

2.3.1.4 Driving Shoe

The drive shoe must be hardened steel and should be replaced or repaired if bent or tarnished. The penetration edge of the drive should be slightly rounded. The thickness of the driving shoe is 0.10 ± 0.02 inches (2.54 ± 0.25 mm) and the inner diameter is 1.375 ±0.005 inches (34.93 ± 0.13 mm).Length 1.0 to 2.0 inch (25 to 50 mm).

Figure 2. 3: Measurement of Driving Shoe Thickness

2.3.1.5 Hammer and Anvil

The hammer must weigh 140 ± 2lb (63.50 ± 0.91 kg) and must be an unyielding metallic mass. The hammer must strike the anvil and make contact between the steel and the steel as it falls.

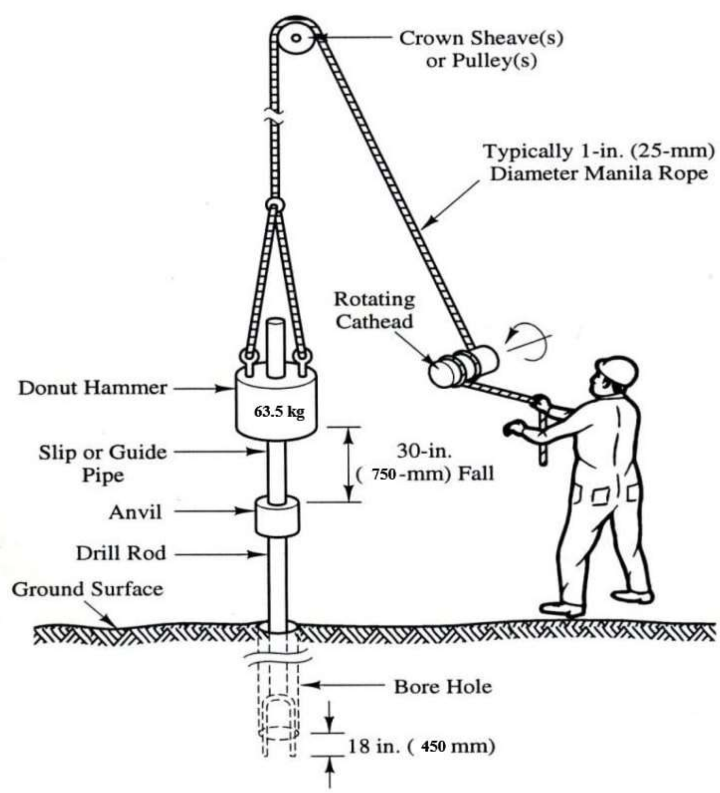

Figure 2. 4: Standard Work Maintain (Image Source: civiltutors.com)

2.3.2 Standard Test Procedure

The Standard Penetration Test (SPT) describes a method of driving a split-barrel sampler to obtain a representative sample of disturbed soil for identification purposes and to measure the in-situ resistance of the soil to application penetration sampler. After drilling the borehole to the required depth, excess soil in the borehole was removed and a clearance of approximately 0.1 feet recorded and prepared for testing. The split spoon sampler is then placed into the borehole by attaching it to the end of the drill rod. The anvil is attached to the top of the sampling rod and the hammer is positioned. During this time, the sampler must not fall to the ground. Then the dead weight of the sampler, guide rod and anvil with hammer rests on the bottom of the borehole. The sample start depth was recorded as approximately 0.1 feet and was compared with the cleaning depth to confirm that no excavation was taking place below the borehole. The drill rod is marked with chalk in three successive lines, extending 6 inches (0.5 ft) from each measurement so that sample progress can be easily observed for every 6 inches (0.5 ft) below blow hammer effect. The Standard Penetration Test (SPT) is performed by dropping a 63.5 ± 0.9 kg (140 ± 2 lb) free-falling hammer onto the drill rod from a height of 30 ± 1 inch (2.5 ± 2 lb). 0.083 ft) to the penetration of a split spoon sampler fitted with a drill rod. Penetration is made with a standard depth of 18 inches (1.5 ft) into the ground. The number of blows required to penetrate each 6-inch (0.5-foot) increment is recorded. The first 6 inches (0.5 ft) is considered the seating drive. The total number of blows required for the second and third 6 inches (0.5 ft) Penetration is called the SPT N value in blows per foot. The test is performed at 5 ft intervals at a specified depth. The device consists of a steel driving-shoe, a split bisecting along the longitude, a ball check, a vent and a coupling at the top. Coupling connects the sampler to the drill rod. Also 30 inch free falling height is maintained by auto hammer operation.

2.4 Factors Affecting the Standard Penetration Test (SPT)

Through Sherif and Radding's Standard Penetration Test (SPT) Correction (2001), Schmertmann (1978) and Kovacs and Salomone (1982) identify the most significant factor affecting the measured N value as the amount of energy delivered to the drill rods. They indicated that the energy delivered to the rods during the Standard Penetration Test (SPT) can vary from about 30% to 80% of the theoretical maximum. The factors affecting the N-value may cause of both the deviation of equipment standard and the deviation of standard test procedure. Procedures that may affect the measured N-values through [1] are shown here.

Table 2. 1: Factors Affecting SPT N-Value with Respect to Equipment

Equipment	Effect
If standard quality of driving shoe is not maintained.	Any type of crack, rust or any damage may be observed in the driving shoes. If the edge of the driving shoe is too sharp, there will be more penetration per blow. Consequently the SPT N value will be lower. Driving shoe thickness 2.54 ±0.25 mm, inner diameter 34.93 ± 0.13 mm and length 25 to 50 mm should be maintained as per ASTM standards to get correct results.
If split spoon is not maintained as per standard.	Accurate disturbed soil samples cannot be collected from deep in the soil. So, length 457 to 762 mm inner diameter 38.1±1.3 mm outer diameter 50.8 ±1.3 mm must be maintained as per standard.
Not using a guide rod	Incorrect N-value earned.
Insufficient borehole cleaning	The sample should be collected after boring a certain amount. Applying SPT only partially to the core soil can cause sludge or solids to get trapped in the sampler and cause compression of the driving shoe as well as increase the number of blows. Sample should be collected from borehole after cleaning enough borehole to get SPT -N value.
Using a bore hole that is too large	Holes larger than 100mm in diameter should not be used. Using a larger diameter may result in decreases in blows calculation.

Equipment	Effect
Sampler clogged with gravel	The higher blow of hits occurs when gravel clogs the sampler, the resistance of loose sand may be overestimated.
Plugged casing	High N values may be observed for loose sand when sampling below the groundwater table. The hydrostatic pressure causes the sand to rise and Plug the casing.
Using a sampler head	The sampler head through which the sample is retrieved accurately. And the sampler head needs to have a steel ball inside. Which does not allow water to enter the sample.
Sampler clogged with gravel	Penetration is reduced when gravel, wood or tree roots are stuck to the sample. As a result the SPT N value increases.
Not using correct weight	Drillers regularly supply drop hammers in different weights, from standard up to 10 lbs. And the heavier the hammer, the more energy will be transferred to the anvil per blow. As a result the SPT N value will be lower. Again, if the weight of the hammer is less, less energy will be transferred to the anvil, resulting in a higher SPT N value. So as per standard SPT hammer weight should be maintained at 140±2 lb.
Weight does not hit the drive shoe concentrically	Impact energy decreases, N value increases.
Not using a water circulation system	If a water circulation system is not used, it may take longer for the soil below the deep pit to loosen. Also it becomes difficult to remove the wet water dug in boreholes. But water circulation systems can quickly remove wet water from excavated soil and boreholes. Its use is important for cleaning the borehole and loosening the subsoil.

Table 2. 2: Factors Affecting SPT N-Values Respect of Test Procedure

Procedure Standard	Effect
Operator Behavior	In the absence of the site engineer during the work, the workers are evading the work. In that case, instead of collecting data after 5 ft, data is collected after 10 ft. Also gives wrong information to Site Engineer. Which hinders accurate soil information verification. So it is important for the site engineer to be on the site during the work.
Drilling Method	Using a rig can vary the number of blows on the same ground. Sometimes pebbles or tree roots are stuck with the sample to increase the number of blows in penetration. As a result SPT- N value is higher.
Incorrect drilling system	If chisel is not used while drilling the borehole and data is collected without removing loose soil and water from the borehole. If the driving shoe is excessively sharp and the hammer weight is too low or too high, the result can greatly affect the correct result. Hence the works should be maintained as per ASTM standards.
Insufficient supervision	Samples should be collected after adequate cleaning of the borehole. Otherwise, the driving shoe may contract when gravel or hard materials collide with the driving shoe. As a result, the number of injuries may increase. As a result the SPT N value will be higher. Hence sufficient amount of loose soil should be removed from the borehole and sample should be collected.

2.6 Standard Penetration Test (SPT) Hammer Energy

Due to the use and acceptance of various types of hammer systems, the energy delivered to the sampler might vary substantially. Donut hammer, safety hammer, and auto hammer types are employed in Standard Penetration Test (SPT), although the manually controlled donut hammer system is the primary focus of this study.

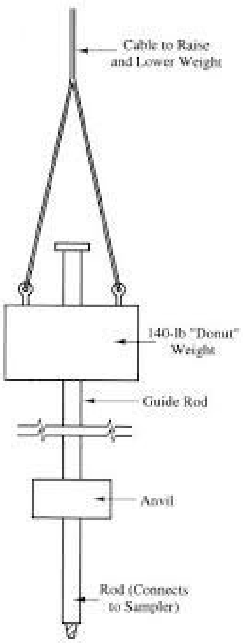

Figure 2. 5: Donut Hammer (Image Source: www.researchgate.net)

The hammer used in the Standard Penetration Test (SPT), which weighs 63.5 kg (140lb), must be a hard-metallic mass. The SPT hammer has a 4200lb-in theoretical energy (473 joules). In a study by kovacs on energy calibration, the average energy ratio for a donut hammer was about 45%, but the energy standardization at 60% of theoretical energy was developed using information gathered in the US and other nations.

Theoretical input Energy = W × h

= 140 × 30

= 4200lb-in

2.7 Correction for Standard Penetration Test (SPT)

The SPT-N value can be impacted by a wide range of circumstances that are permitted by [1] however, only the SPT value for field operations is presented here and is pertinent to this research effort despite the fact that other authors have suggested correction factors for various aspects.

It is reasonable to standardize the field SPT value as a function of reduced input driving energy and its dispersion around the nearby soil based on field observations. By converting N to N60, the various testing procedure factors can be at least somewhat compensated for [1]

$$N_{60} = \frac{E_H C_B C_S C_R N}{0.60}$$

Where,

N_{60} = Corrected SPT N-value for field Procedures.

E_H = Hammer efficiency (Table 2.3)

C_B = Borehole diameter correction (Table 2.4)

C_S = Sampler correction (Table 2.4)

C_R = Rod length correction (Table 2.4)

N = Measured SPT N-value in field

This correction is to be done irrespective of the type of soil.

Table 2. 3: Correction table for SPT hammer efficiencies (BNBC 2015 Table 6.D.4)

Hammer Type	Hammer Release Mechanism	Efficiency, E_H
Automatic	Trip	0.70
Donut	Hand dropped	0.60
Donut	Cathead + 2 turns	0.50
Safety	Cathead + 2 turns	0.55-0.60
Drop/Pin	Hand dropped	0.45

Table 2. 4: Borehole, Sampler and Rod Correction Factors (BNBC 2015 Table 6.D.5)

Factor	Equipment Variables	Correction Factor
Borehole diameter factor, C_B	65 – 115 mm (2.5-4.5 in)	1.00
	150 mm (6 in)	1.05
	200 mm (8 in)	1.15
Sampler correction, C_S	Standard sampler	1.00
	Sampler without liner (not recommended)	1.20

Factor	Equipment Variables	Correction Factor
Rod length correction, C_R	3 – 4 m (10-13 ft)	0.75
	4 – 6 m (13-20 ft)	0.85
	6 – 10 m (20-30 ft)	0.95
	>10 m (>30 ft)	1.00

2.8 Past Research in Bangladesh

In Bangladesh, standard penetration test has been utilized extensively in geotechnical engineering practice for a very long period. Research by [1] should that did "effects of drop energy on SPT value," and parts of that research align with the goal of the current investigation. Their research examine the energy efficiency of manually operated hammers. According to the author, hammers have an energy efficiency of 103.4% to 114.9% apart from the context of Bangladesh, several related studies have notably found that the energy ratio varies from 30% to 90%. In their study, the practicing hammer weight was 4.73 lb heavier than the standard weight. The internal dia of the sampler received 5.9 mm more than the standard. The thickness of the driving shoe was found to be 0.54 mm less than the standard value. They collected data from a total of five boreholes from one site. A total of 2412 hammer blows were recorded. Whereas only 198 blows were sustained from the standard free-falling height of 30 inch, which is 8.2% of the total blows. 1837 blows were released from heights greater than the standard free-falling height of 30 inch, accounting for 76.2% of all blows. 377 blows were released from heights less than the standard free-falling height of 30 inch, accounting for 15.6% of the total blows.

CHAPTER THREE
DATA COLLECTION AND ANALYSIS

3.1General

This chapter discusses site selection, data collection, and data analysis. Show the data collection procedure along with the dimensions of the SPT hammer, the split spoon sampler, the driving Shoe, and the weight and free- falling height of the SPT hammer. In addition, data analysis and energy efficiency estimates of the practice hammer are also presented.

3.2 Site Selection

A site was selected for field data collection in sector-17 of Uttara Phase III project area in Dhaka. The site is proposed for a residential building and auto hammer operated SPT rig is actually used at the site for soil exploration. Whereas a total of 3 boreholes were conducted and SPT hammer free height data was collected from 1 of the 3 boreholes in this study. The borehole was extended to a maximum depth of 120 feet and data was collected up to 120 feet. BRTA Vehicle Inspection Center of Rajshahi City, Rajshahi has been selected for field data collection of 10 storey building project. The site is proposed for a commercial building. A total of 5 boreholes were operated and SPT hammer free-falling height data was collected from 1 of the 5 boreholes in this study and the boreholes extended to a maximum depth of 100 feet was done and data was collected up to 100 feet. Shilinda botala field of Rajshahi city, Rajshahi was selected for field data collection. The site is proposed for a residential building and a total of 2 boreholes were drilled And SPT hammer free height data was collected from 1 of the 2 boreholes in this study. The borehole extended to a maximum depth of 100 feet and data was collected up to 100 feet. Selection A site was selected for field data collection near Dhaka Jatrabari Jurain Medical Road, Fans Mosque. The site is proposed for a residential building and where a total of 3 boreholes were drilled. And SPT hammer free height data was collected from 1 out of 3 boreholes in this study. The borehole was extended to a maximum depth of 100 feet and data were collected up to 65 feet. A site near Dhaka Konabari University was selected for field data collection. The site is proposed for a residential building and where a total of 3 boreholes were operated and SPT hammer free height data was collected from 1 of the 3 boreholes in this study. The borehole was extended to a maximum depth of 100 feet but data was collected down to 60 feet. A site was selected within Dhaka Heart Institute. A total of 3 boreholes were drilled at the site proposed for oxygen pipe installation and SPT hammer free height data was collected from 1 of the 3 boreholes in this study. A maximum of 20 feet of data was collected in the borehole. Also, data was collected from two farms khilkhet and bashundhara all sites is shown (Figure 3.1).

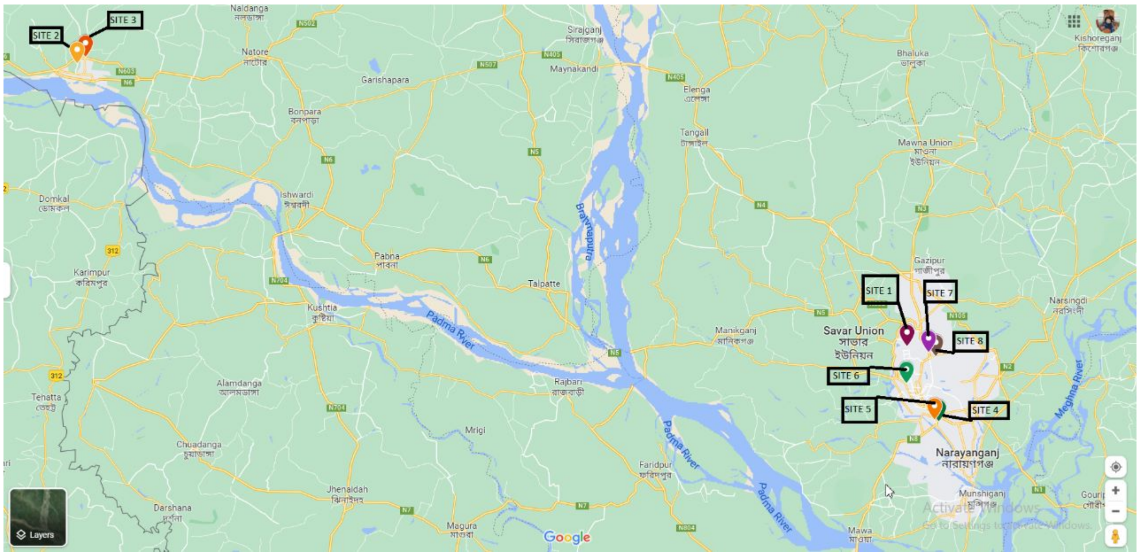

Figure 3. 1: Different Site Location (From: Google Map)

Table 3. 1: Site Name According Their Location

Site No	Location	Coordinate
Site 1	Uttara, Dhaka	23°50'34.2"N 90°22'19.0"E
Site 2	BRTA, Rajshahi	24°24'27.8"N 88°36'33.9"E
Site 3	Shilinda, Bottola, Rajshahi	24°23'40.1"N 88°35'29.6"E
Site 4	Kona Bari, Dhaka	23°41'45.2"N 90°26'20.4"E
Site 5	Jurain, Dhaka	23°41'58.1"N 90°25'48.2"E
Site 6	National Institute of Cardiovascular Diseases, Dhaka	23°46'13.4"N 90°22'10.9"E
Site 7	Khilkhet, Nikunjo 2, Road 2, Dhaka	23°49'54.8"N 90°25'04.1"E
Site 8	Balk I, Road 21, Bosundhora, Dhaka	23°49'21.7"N 90°25'57.5"E

3.3 Data Collection Procedure

Four auto hammer and four manual SPT rigs were selected in this study for data collection. First the SPT equipment used by the rig operator is thoroughly cleaned. And is closely inspected, and the internal diameter of the split spoon sampler is divided in half, the length of the drill rod, the inner and outer diameter, the thickness of the cutting shoe and its size. Hammer weight is measured directly by digital weighing machine. Also the difference in hammer weight is calculated by multiplying the actual mass of the hammer by the unit weight of steel. The exact free-falling height of the hammer is measured by high definition video recording. To establish a reference point for free-falling height in the case of manual hammers, anvils are marked 3 inches below and 3 inches above the standard free-falling height of 30 inch. Free falling height data were recorded at 5 feet away from the boreholes of six sites and at depths of 120 feet, 100 feet and 60 feet, 65 feet, 20 feet. Each stroke is the correct free-falling height. Measurements and calculations are then performed by playing back video shots in slow motion. Also data was collected from 2 firms. Detailed data collection procedures and recorded data are shown below.

Figure 3. 2: Site Working Time

3.3.1 Dimensions and Weight of SPT Hammer

Figure 3. 3: The hammer is accurately measured in kg by digital weight machine.

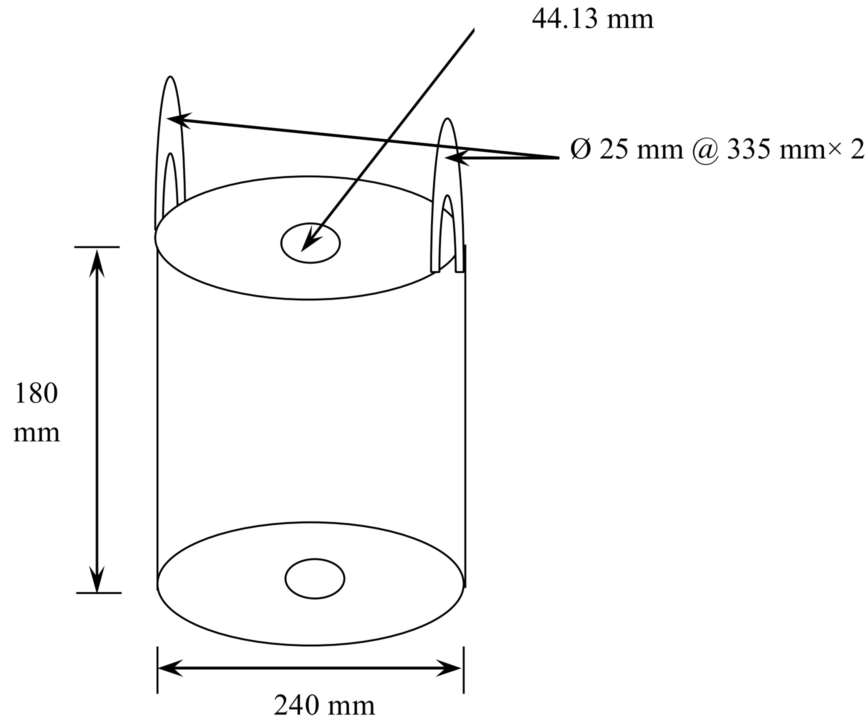

Figure 3. 4: Dimensions of practicing SPT hammer

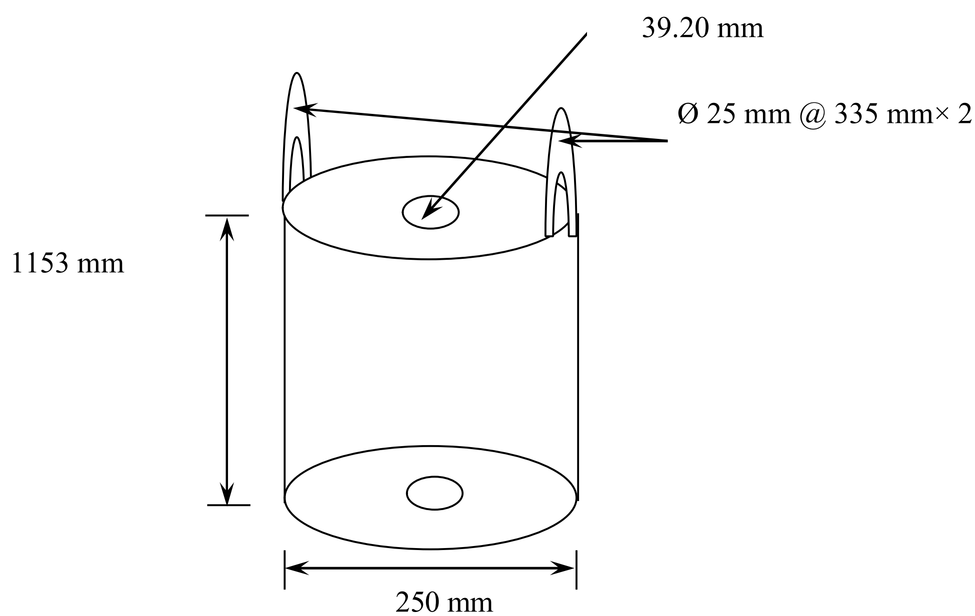

Figure 3. 5: Dimensions of practicing SPT hammer

Measurements obtained in the field,

L = 180 mm 18 cm)

D = 240 mm (24 cm)

$D_{(hollow)}$ = 44.13 mm (4.4 cm)

Hanger rod = Ø 25 mm @ 335 mm (33.5 cm) × 2

From the measurement (Figure 3.4), the actual weight of the hammer can be measured as -

Actual volume of hammer $= ((\pi\times24^2)/4\times18) - ((\pi\times4.4^2)/4\times18)$

$= 7869.312606\ cm^3$

$= 7869.312606/100^3\ m^3$

Weight of Hammer $= 0.007869312606\ m^3 \times 7860$ kg [$1m^3$ steel = 7860 kg]

= 61.85279708 kg

Weight of hanger rod = (33.5 × 2) / 100

= .67 × 3.858 [19 mm Ø rod] [25 mm Ø = 3.858 kg/m]

= 2.58486 kg

Actual weight of hammer = 61.85279708 + 2.58486

= 64.4 kg

= 141.98 lb

The weight of the hammer was found 141.98 lb (64.4 kg) during test, which is lower than the standard weight as specified in the ASTM.

Measurements obtained in the field,

L = 153 mm (15.3 cm)

D = 250 mm (25 cm)

$D_{(hollow)}$ = 39.20 mm (3.92 cm)

Hanger rod = Ø 25 mm @ 335 mm (33.5 cm) × 2

From the measurement (Figure 3.5), the actual weight of the hammer can be measured as -

Actual volume of hammer = $((\pi \times 25^2)/4 \times 15.3)$ - $((\pi \times 3.92^2)/4 \times 15.3)$

= 7325.71818 cm^3

= 7325.71818 /100^3 m^3

Weight of Hammer = 0.00732571818 m^3 × 7860 kg [1m^3 steel = 7860 kg]

= 57.58 kg

Weight of hanger rod = (33.5 × 2) / 100

= .67 × 3.858 [19 mm Ø rod] [25 mm Ø = 3.858 kg/m]

= 2.58486 kg

Actual weight of hammer = 57.58 + 2.58486

= 60.16 kg

= 132.6lb

The weight of the hammer was found 132.6 lb (60.16 kg) during test, which is less than the standard weight as specified in the ASTM.

Table 3. 2: SPT hammer weight data of eight sites

Site No	Hammer Type	ASTM Standard	Actual weight of Hammer
Site 1	Auto Trip 1	140 ± 2 lb 63.5 ± 0.91 kg	139.11 lb/63.10 kg
Site 2	Auto Trip 2		139.33 lb/ 63.2 kg
Site 3	Auto Trip 3		140.54 lb / 63.75 kg
Site 4	Auto Trip 4		136.69 lb /62.0 kg
Site 5	Manual 1		139.11 lb/63.10 kg
Site 6	Manual 2		140 lb/63.50 kg
Site 7	Manual 3		141.98 lb/64.4 kg
Site 8	Manual 4		132.6 lb/60.16 kg

The external condition of the hammers was carefully examined for a total of eight sites in the study. And no major damage was observed except for some dirt accumulated on the surface of the hammer. Rig operators rarely clean up dirt and mud. But in this study the outer surface was first cleaned by the rig operator to get the correct dimensions of the hammer. Measurements were made by direct digital weighing machine. It is also calculated by multiplying the actual mass of the hammer by the unit weight of steel. Hammer width and height and diameter of donut sections were measured to verify differences. Length and diameter of hanger rods are measured in mm by vernier scale. Hammer weight is estimated by multiplying the actual volume of the hammer by the unit weight of steel and the actual mass of the hammer. Recorded data and details above (Table 3.2) shows the recorded data and details of the eight sites.

3.3.2 Dimension Split-Spoon Sampler

Figure 3. 6: Length Measurement of Split Spoon Sampler

Table 3. 3: Dimension of split spoon sampler data of eight sites

Site No	ASTM	Length	Inner Diameter	Outside Diameter
Site 1	Length 457 to 762 mm (18 to 30inch) Inner diameter 38.1±1.3mm (1.50±0.05inch) Outer Diameter 50.8 ± 1.3 mm. (2.00±0.05inch)	600 mm	37.86 mm	52.42 mm
Site 2		605 mm	36.54 mm	52.02 mm
Site 3		615 mm	38.26 mm	52.62 mm
Site 4		596 mm	37.95 mm	52.02 mm
Site 5		587 mm	32.83 mm	52.08 mm
Site 6		607 mm	36.19 mm	50.66 mm
Site 7		609 mm	38.96 mm	52.25 mm
Site 8		610 mm	38.19 mm	51.80 mm

The physical condition of eight different split spoon samplers was carefully examined both internally and externally for a total of eight study sites. And exact dimensions are measured in mm by vernier scale. No major damage was observed on the outer surface, but the inner surface was uneven due to rust and corrosion on the split spoon in 2 places. The internal surface of the sampler was thoroughly washed before measuring the internal diameter. During the test, internal diameter, 37.86 mm, 36.54 mm, 38.26 mm, 37.95 mm, 32.83 mm, 36.19 mm, 38.96 mm, 38.19 mm. is available and outer diameter, 52.42 mm, 52.02 mm, 52.62 mm, 52.02 mm, 52.08 mm, 50.66 mm, 52.25 mm, 51.80 mm and length of split-spoon sampler, 600 mm, 605 mm, 615 mm, 596 mm, 587 mm, 607 mm. mm, 609 mm, 610 mm, are available, according to the ASTM specified standard Split Spoon sampler should have inner diameter, 38.1 ± 1.3 mm, outer diameter, 50.8 ± 1.3 mm and length 457 to 762 mm. The difference is shown (Table 3.3)

3.3.3 Dimension of Driving Shoes

Diving shoes should be of hardened steel as per ASTM for driving and when it is cracked or damaged, it should be replaced or repaired promptly. The edge of the driving-shoe hole is slightly rounded and has a thickness of 2.54 ± 0.25 mm (0.01 ± 0.02 in) and an internal diameter of 34.93 ± 0.13 mm (1.375 ± 0.005 in). The length should be 25 to 50 mm (1 to 2 inches). During testing at eight different sites, the physical condition of the driving shoes was carefully examined internally and externally and no marks or deformations were observed. The correct thickness of the penetration edge is obtained. No rust was detected on the inner surface of the driving shoe. It is found clean and smooth. Driving shoes were thoroughly cleaned for accurate thickness measurement. And the thickness is precisely measured in millimeters using a Vernier scale. Driving shoe thickness during testing. Inside diameter of driving shoe and length recorded according to the standards specified in ASTM and the details and differences are shown in the table above. The penetration edge has been obtained. No rust was detected on the inner surface of the driving shoe. It is clean and smooth. For accurate thickness measurement the driving shoe is thoroughly cleaned and the thickness is measured to the nearest mm using a Vernier-scale. The driving shoe thicknesses during the test were 1.54 mm, 3.03 mm, 2.54 mm, 2.64 mm, 2.74 mm, 3.16 mm, 2.43 mm, 3.83 is available. Inner diameter of driving shoe is 35.76 mm, 35.23 mm, 35.52 mm, 3.70mm, 36.15 mm, 35.02 mm, 34.83 mm, 34.79 mm is available. As well as driving shoe length 56 mm, 57 mm, 55 mm, 59 mm, 60 mm, 50 mm, 50 mm, 55 mm is available.

Figure 3. 7: Thickness Measurement of Driving Shoe

Table 3. 4: Dimension of driving shoes data of eight sites

Site No	ASTM	Thickness	Inner Diameter	Length
Site 1	Thickness 2.54 ± 0.25 mm (0.10 ± 0.02inch) Inner diameter 34.93 ± 0.13mm (1.375 ±0.005inch) Length 25 to 50 mm (1 to 2 inch)	1.54 mm	35.76 mm	56 mm
Site 2		3.03 mm	35.23 mm	57 mm
Site 3		2.54 mm	35.52 mm	55 mm
Site 4		2.64 mm	35.70 mm	59 mm
Site 5		2.74 mm	36.15 mm	60 mm
Site 6		3.16 mm	35.02 mm	50 mm
Site 7		2.43 mm	34.83 mm	50 mm
Site 8		3.83 mm	34.79 mm	55 mm

Water Circular Tub for SPT Test: Water circular tub is mainly used to flow water through hose pipe drill pipe at many forces. As a result the excavated soil of the borehole helps to rise up through the wet water.

Figure 3. 8: Water Circulation Tub for SPT Test

Drill Rod: When the borehole is done up to the specified depth, it is inserted into the borehole by attaching a split spoon to the drilling rod. Three marks are made on the drilling rod at 6 inch intervals for SPT test. The first 6 inch out of total 18 inch is considered as for setting time spoon. The sum of the total blows is counted as the SPT N value for the next 6inch + 6inch penetration. Drill rod should be 10 ft as per ASTM.

Figure 2. 6: SPT Drill Rod Image Source Site

Rope Tie: Rope ties play an important role during standard penetration testing. During work, rope binding should be carefully monitored. Because if the rope breaks or slips out of the hand during handling, it can cause great danger or damage. So, should work according to the standard rules.

Figure 3. 9: Rope Tie as Per Standard Rules

Table 3. 5: Comparative Analysis between Auto Trip & Manual Rig Systems

Items	ASTM	Manual 1	Manual 2	Manual 3	Manual 4	Auto Trip 1	Auto Trip 2	Auto Trip 3	Auto Trip 4
Hammer Weight	140 ± 2 lb	139.11 lb	140 lb	141.98 lb	132.6 lb	139.11 lb	139.33 lb	140.54 lb	136.69 lb
Driving Shoes Thickness	2.54 ± 0.25 mm	1.54 mm	3.03 mm	2.54 mm	2.64 mm	2.74 mm	3.16 mm	2.43 mm	3.83 mm
Driving Shoes Inner Diameter	34.93 ± 0.13mm	35.76 mm	35.23 mm	35.52 mm	35.70 mm	36.15 mm	35.02 mm	34.83 mm	34.79 mm
Driving Shoes Length	25 to 50 mm	56 mm	57 mm	55 mm	59 mm	60 mm	50 mm	50 mm	55 mm
Split Spoons Length	457 to 762 mm	600 mm	605 mm	615 mm	596 mm	587 mm	607 mm	609 mm	610 mm
Split Spoons Inner Diameter	38.1 ± 1.3 mm	37.86 mm	36.54 mm	38.26 mm	37.95 mm	32.83 mm	36.19 mm	38.96 mm	38.19 mm
Split Spoons Outer Diameter	50.8 ± 1.3 mm	52.42 mm	52.02 mm	52.62 mm	52.02 mm	52.08 mm	50.66 mm	52.25 mm	51.80 mm

The study is done by four auto trip hammer and four Manual rig operators and according to ASTM, the difference between auto trip and manual work is determined. For the research mainly 6 sites and 2 firms were visited to collect data. The study shows that according to ASTM the free falling height of auto hammer is maintained at 30 inches but manual hammer standards 30 inch height is not maintained.

According to SPT Standards the weight of the hammer should be 140 ± 2 Ib but according to the research given in the above table the weight of the Manual 4 hammer is 132.6 lb and the weight of the Auto Trip Hammer is 136.69 lb.

According to ASTM the thickness of the driving shoes should be 2.54 ± 0.25 mm but in the study manual 1 & manual 2 - 1.54 mm & 3.03 mm are found during testing. Also available in auto trip 2 & auto trip 4 - 3.16 mm & 3.83 mm. which is not maintained by ASTM. As a result the thicker the driving shoe the sharper the hammer will have more penetration per blow. And that affects the SPT N value. At the same time the length of the driving needle should be 25 to 50 mm but in researches it is found to be 5mm-10 mm longer than ASTM

3.3.4 Measurement of Free-Falling Height

Figure 2. 7: Marking The Anvil and free free-falling height Measurement Auto & Manual Hammer

For site1 easy to maintain free- falling height with auto hammer. We know as per ASTM the free- falling height should be 30 inch. If the height is greater than 30 inches for free- falling, the force effect on the sampler will be greater. As a result SPT N value will decrease, hence under estimation of soil. Again, if the free- falling height is less than 30inch, the effect of force on the simpler will be less and the SPT N value will be higher. Hence over estimation of soil strength. In case of auto hammer this 30inch height can be easily maintained resulting in accurate soil strength.

This study fixed the free-falling height of the hammer at 30 inch by high definition video recording. A standard free-falling height of 30 inches as shown in (Figure 3.7)free-falling height data were recorded from a borehole at a depth of 120 ft at 5-ft intervals. Each hit was then counted by playing the video recording in slow motion. The recorded SPT N-values with depth are given in Table 3.5 for one borehole.

For site 2 it is quite difficult to maintain the free-falling height of the hammer in a manually operated hammer. The free-falling height of the hammer can significantly affect penetration resistance. If the free-falling height is greater than the standard free-falling height of 30 inches, more energy will be transferred to the sampler resulting in a lower SPT N-value, hence under estimation of soil strength. On the other hand, if the free-falling height is less than the standard free-falling height of 30 inch, less energy will be transferred to the sampler resulting in a higher SPT N-value, hence over estimation of soil strength.

This study measured the exact free-falling height of the hammer through high definition video recording. To establish the reference point for the free-falling height, the anvil is well marked at intervals of 3 inches below and above the standard free-falling height of 30 inch as shown in (Figure 3.8) free-falling elevation data were recorded from four boreholes 60 ft by 65 ft and 100 ft deep at 5-ft intervals. The exact free-falling height of each push was then measured by playing the video recording in slow motion. The measured free-falling height data and recorded SPT N-values with depth are given in Table 3.6 to Table 3.9 for the four boreholes.

3.3.5 Estimation of Energy Efficiency

The SPT hammer energy efficiency can be expressed as –

$$\text{Energy efficiency, } \mathrm{E_r}(\%) = \frac{\textit{Actual hammer energy to the sampler}}{\textit{Theoretical input energy}} \times 100$$

There are several factors contribute to the actual hemmer energy to the sampler. But in this study, the actual hemmer energy to the sampler for a particular depth is estimated by multiplying the actual free-falling height of the hammer for each blow and the actual weight of the hammer. A representative calculation is shown below at 5 ft depth for borehole 1.

Actual hemmer energy = (139.11 × 30) + (139.11 × 30)

= 8346.6 lb-in

The theoretical input energy is the product of the hammer weight and the height of Free-falling. The theatrical input energy for a particular depth is estimated by multiplying the SPT N value at that depth, the standard hammer weight (140 lb) and the standard free-falling height (30 inch.

A representative calculation is shown below at a depth of 5 ft for Borehole

Theoretical input energy = Wh × N-value

= 140 × 30 × 2

= 8400lb-in

So, the energy efficiency can be estimated as –

Energy efficiency, $Er(\%) = \frac{8346}{8400} \times 100 = 99.4\%$

The actual estimated actual hammer energy from the sampling, the theoretical input energy and the practicing energy efficiency with depths are given in (Tables 3.6 to 3.8) for the five site boreholes.

Table 3. 6: Free-falling height and actual energy efficiency of SPT auto hammer for site-1

Depth (ft)	Free- Falling Height of SPT Hammer		SPT-N Value	Actual hammer energy (lb-in)	Theoretical input energy (lb-in)	Actual Energy Efficiency Er (%)
	Free-falling height of second 0.5 ft/6 (inch)	Free-falling height of third 0.5 ft/ 6 (inch)				
05	30	30	2	8346.6	8400	99.4%
10	30	30	3	12519.9	12600	99.4%
15	30	30	3	12519.9	12600	99.4%
20	30	30	5	20866.5	21000	99.4%
25	30	30	3	12519.9	12600	99.4%
30	30	30	4	16693.2	16800	99.4%
35	30	30	4	16693.2	16800	99.4%
40	30	30	11	45906.3	46200	99.4%
45	30	30	9	37559.7	37800	99.4%
50	30	30	9	37559.7	37800	99.4%
55	30	30	12	50079.6	50400	99.4%
60	30	30	21	87639.3	88200	99.4%
65	30	30	17	70946.1	71400	99.4%
70	30	30	15	62599.5	63000	99.4%
75	30	30	16	66772.8	67200	99.4%
80	30	30	10	41733	42000	99.4%
85	30	30	10	41733	42000	99.4%
90	30	30	21	87639.3	88200	99.4%
95	30	30	16	66772.8	67200	99.4%
100	30	30	23	95985.9	96600	99.4%
105	30	30	60	250398	252000	99.4%
110	30	30	60	250398	252000	99.4%
115	30	30	59	246224.7	247800	99.4%
120	30	30	50	208665	210000	99.4%

Table 3. 7: Free-falling height and actual energy efficiency of SPT manual hammer for site-2

Depth (ft)	Free- Falling Height of SPT Hammer		SPT-N Value	Actual hammer Energy (lb-in)	Theoretical Input energy (lb-in)	Actual Energy Efficiency Er (%)
	Free-falling height of second 0.5 ft/6 (inch)	Free-falling height of third 0.5 ft/ 6 (inch)				
05	30,31	30	3	12659.01	12600	100.5%
10	30	29	2	8207.49	8400	97.7%
15	32	29,31	3	12798.12	12600	101.6%
20	33,32,32	31,30,30,31	7	30465.09	29400	103.6%
25	32,33,32,31	32,30,33,33,30,32	10	44236.98	42000	105.3%
30	30,29,29,28	29,27,27,32,30	9	36307.71	37800	96.1%
35	33,28,29,33,30,32,29	31,31,30,30,32,32,30,27	15	63434.16	63000	100.7%
40	30,30,30,32,30,31,30	29,30,32,30,32,31,29,31,33	16	68163.9	67200	101.4%
45	30,30,29,30,32,31,30	30,31,30,31,30,30,27	14	58565.31	58800	99.6%
50	31,30,30	30,31,30	6	25318.02	25200	100.5%
55	30,32,32,31,30	33,31,30,30,30,29	11	47019.18	46200	101.8%
60	30,31,30,30, 30,31,29	30,30,31,31,31,32,30,30,30	16	67607.46	67200	100.6%
65	30,28,31,30,30, 29,31,30	29,30,32,31,32,31,30,30,27,28	18	74980.29	75600	99.2%
70	30,30,31,32,29,30,	30,32,30,32,28,30,27,29,	14	58426.2	58800	99.4%
75	29,31,30,30,30, 31,30,31,32,31	31,30,31,30,32,29,30,29,31, 30,31,32,30,32	24	101967.63	100800	101.2%
80	30,30,30,28,28,30, 32,31,29,28	30,30,30,30,32,30,31,30, 31,30,31,31,32	23	96542.34	96600	99.94%
85	29,30,28,29,30,28, 28,27,30, 30,28,30,29,27,28, 29,27,29,30,30	27,30,29,30,28,28,30, 28,30,30,30, 30,30,28,31, 30,30,30,33	39	158307.18	163800	96.6%
90	30,30,29,29,28,30,	29,30,30,30,31,30,29,30,30,	50	207552.12	210000	98.8%

Depth (ft)	Free- Falling Height of SPT Hammer		SPT-N Value	Actual hammer Energy (lb-in)	Theoretical Input energy (lb-in)	Actual Energy Efficiency Er (%)
	Free-falling height of second 0.5 ft/6 (inch)	Free-falling height of third 0.5 ft/ 6 (inch)				
	31,30,28,30,30,30,30,30,29,30,29,30, 30,31,30,30,31,29,30,29,30,31	28,30,29,27,31,30,32,30,30, 31,30,31,30				
95	30,33,30,30,29,28,30,28,30,30,30,31,30,28,30, 30,30,30,31,30	31,29,28,30,30,30,33,30,30,31,29,30, 30,29,29,30,30,30,30,29,27,31,30,30, 31,30	46	191276.25	193200	99.0%
100	29,30,32,31,32,31,30,30,27,28,30,30, 28,28,30,29,31,29,28,30,27,30,29,30, 28,28,30,28,30,30,30,30,28,31,30,30, 33	30,29,29,30,28,30,30,30,29, 30,30,29,29,30,30,31,32,30	55	226888.41	231000	98.2%

Table 3. 8: Free-falling height and actual energy efficiency of SPT manual hammer for site-3

Depth (ft)	Free- Falling Height of SPT Hammer		SPT-N Value	Actual hammer energy (lb-in)	Theoretical input energy (lb-in)	Actual Energy Efficiency Er (%)
	Free-falling height of second 0.5 ft/6 (inch)	Free-falling height of third 0.5 ft/ 6 (inch)				
05	29,32,33,	30,31,31,29,33,32	9	39200	37800	103.7%
10	30,33,30,31,31,	29,32,30,31,32,32	11	47740	46200	103.3%
15	30,32,29,30,32,29,30,	32,29,31,30,32,28,27,31	15	63280	63000	100.4%
20	31,28,31,27,30,	31,30,30,33,34,29,27,30	13	54740	54600	100.3%
25	32,29,30,33,28,30	31,33,28,30,34,29,29,33,27,	15	63840	63000	101.3%
30	27,30,30,29,32,28,30	28,30,33,28,29,27,32,30 30,32,27,29,30,31,28	22	91000	92400	98.5%
35	30,28,31,30,30,28,27, 26,27,29,31,34,26	31,33,30,31,28,27,30,33,28, 27,30,30,26,28,	27	110460	113400	97.4%
40	33,30,31,30,28,30,30,33,28, 30,29,30,28	29,32,33,30,35,30,27,30,27, 30,35,30,34,30,35	28	119980	117600	102.0%
45	27,29,30,27,30,30,36, 33,30,31,32,32,30,28, 29,35	30,30,29,28,36,30,30,28, 31,30,33,29,27,30,25, 30	32	135100	134400	100.5%
50	30,28,26,30,33,30,32, 30,28,29,30,35,30,28	29,32,28,30,33,28,34, 25,3035,31,30,33,28,30,32	30	126980	126000	100.8%
55	29,32,30,28,30,32,32,30,29,27, 29,30,30,31 30,32	32,30,34,33,35,30,32, 27,35,30,28,32,30,27,29, 32,35,29,30,36,30,30	38	163380	159600	102.4%
60	30,28,30,29,30,32,28,27,30,32, 33,30,28,28,30	32,30,35,28,26,29,32, 30,33,30,29,30,27,30,33, 27	31	129640	130200	99.6%
65	28,30,35,30,33,28,30,27,29,35, 30,35,30,28,29	30,27,28,30,35,30,32,33, 30,32,29,35,28,26,30, 35,29,30	33	140840	138600	101.6%

Depth (ft)	Free- Falling Height of SPT Hammer		SPT-N Value	Actual hammer energy (lb-in)	Theoretical input energy (lb-in)	Actual Energy Efficiency Er (%)
	Free-falling height of second 0.5 ft/6 (inch)	Free-falling height of third 0.5 ft/ 6 (inch)				
70	30,31,28,35,27,33,30,34,30,29, 28,27,30,32,31,30,33	32,28,30,33,30,28,27, 29,30,31,35,30,31,30,27,30,32,35,33,29	37	157920	155400	101.6%
75	30,33,29,30,32,27,30,31,31, 30,35,28,27,29,29,30,28,28,29	30,32,28,30,30,33,31,32,27,29,28,33,30,33,29, 30,32,28,30,31,29,30,32,28	43	180740	180600	100.1%
80	29,30,28,30,32,33,30,30,31, 28,29,30,31,27,29,26,34,30, 36,27,26,28	33,26,28,30,28,29,30,28,28,29,27,27,31,28,31, 29,33,30,32,33,29,29,30,32,31	47	195300	197400	98.9%
85	30,28,27,30,31,29,30,27,30, 31,32,30,31,32,33,30,31,32,30, 30,31,27,30,31	28,30,31,27,31,30,27,30,30,27,30,32,30,32,28, 27,27,28,30,32,28,29,30,33,30,27,30,32,	52	195300	218400	89.4%
90	28,32,30,31,30,28,27,29,29, 30,31,30,30,31,30,32,28,29, 30,31,32,30	30,32,28,27,32,30,27,29,30,31,32,30,30,31,32, 33,28,28,30,33,30,28,27,28	46	192360	193200	99.6%
100	30,28,30,33,32,27,28,29, 28,28,29,31,30,33,30,31,30,28,30, 29	28,30,32,28,27,28,30,28,31,30,31,28,28,30,28, 30,29,31,33,31,32,30,30,32,30,31,30,31,28,29	50	208320	210000	99.2%

Table 3. 9: Free-falling height and actual energy efficiency of SPT manual hammer for site-4

Depth (ft)	Free- Falling Height of SPT Hammer		SPT-N Value	Actual hammer energy (lb-in)	Theoretical input energy (lb-in)	Actual Energy Efficiency Er (%)
	Free-falling height of second 0.5 ft/6 (inch)	Free-falling height of third 0.5 ft/ 6 (inch)				
05	30,29	31,30,32	5	21580.96	21000	102.8%
10	30,31	30,29	4	17037.6	16800	101.4%
15	29,31	30,30	4	17037.6	16800	101.4%
20	30,28	30,31,30	5	21155.02	21000	100.7%
25	29,31,29	30,28,30	6	25130.46	25200	99.7%
30	30,32,33	30,32,29,30	7	30667.68	29400	104.3%
35	30,31,29,30,33,30	30,32,30,29,30,32,33,29,30	15	65026.84	63000	103.2%
40	31,30,32,28,30,30,29,30	30,32,30,28,30,28,30,32,27,30,31,30	20	84904.04	84000	101.1%
45	30,31,30,33,29,27,30,30,29	30,32,28,30,27,33,30,29,30,32,30,30	21	89447.4	88200	101.4%
50	30,29,30,32,35,27,29,30, 30,31	30,31,32,30,32,33,27,31,31,3o,30, 31,29	23	99386	96600	102.9%
55	30,32,31,30,32,30,31,30,32, 30,27,30	30,32,30,29,30,31,30,33,33,31,27,30, 29,28,29	27	115997.66	113400	102.3%
60	30,32,29,31,30,31,29,27,30,31 32,33,30,31,27,28,29,30,30, 30,31,32	31,30,30,30,32,31,33,31,32,30,31,30, 31,30,28,27,30,33,28,27,30,31,32,30,31 27,29,30,31,31,30,28,31,30,30,29,30,29	60	256557.86	252000	101.8%
65	30,30,31,29,30,27,29,30,30,28 30,32,27,30	30,31,29,30,32,31,30,30,27,30,29,30,28, 33,28,29,	30	126362.2	126000	100.3%

Table 3. 10: Free-falling height and actual energy efficiency of SPT manual hammer for site-5

Depth (ft)	Free- Falling Height of SPT Hammer		SPT-N Value	Actual hammer energy (lb-in)	Theoretical input energy (lb-in)	Actual Energy Efficiency Er (%)
	Free-falling height of second 0.5 ft/6 (inch)	Free-falling height of third 0.5 ft/ 6 (inch)				
30	35	37	2	9547.2	8400	113.7%
40	30,28,35,34,26,26,25,28,25	35,30,32,35,33,32,30,25,28,29	19	75979.8	79800	95.2%
50	30,29,30,30,29,27,26,24,28,32,30,31,30	26,28,30,29,27,26,24,35,29,30,28,27,30	26	98787	109200	90.5%
60	30,26,29,30,31,28,30,29,32,27,25,27, 24,28,28,30,30,29,30,33,35	30,35,32,30,35,30,32,28,25	30	117748.8	126000	93.5%

Table 3. 11 : Free-falling height and actual energy efficiency of SPT auto trip hammer for site-6

Depth (ft)	Free- Falling Height of SPT Hammer		SPT-N Value	Actual hammer energy (lb-in)	Theoretical input energy (lb-in)	Actual Energy Efficiency Er (%)
	Free-falling height of second 0.5 ft/6 (inch)	Free-falling height of third 0.5 ft/ 6 (inch)				
05	30	30	3	12539.7	12600	99.5 %
10	30	30	8	33439.2	33600	99.5 %
15	30	30	12	50079.6	50400	99.5 %
20	30	30	17	71058.3	71400	99.5 %

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 General

In this study, the field values obtained from five sites were compared according to ASTM standards. Data were collected on SPT hammer weight, split-spoon sampler dimensions, driving shoe thickness and size, sampling rods, and hammer free-falling height from an auto hammer operated SPT rig and a manually operated SPT rig. The results obtained in this study are presented and compared with ASTM standards. Infiltration resistance results and the significance of soil strength are also discussed.

4.2 Hammer Weight

In this study, eight hammer weights were measured from eight different sites and the actual values obtained from the field were compared with ASTM standards. According to ASTM standards, the weight of the hammer should be 140 ± 2 lb/63.5 kg. If the hammer weight is less than the ideal weight, less energy will be transferred to the anvil per blow. Consequently the SPT N value will be greater than the ideal SPT N value and more force will be transferred to the anvil if the hammer weight is greater than the ideal weight. The resulting SPT N value will be lower or higher than the ideal SPT N value. Detailed information and differences are shown below Table 4.1

Table 4. 1: Comparison of SPT hammer weight with the ASTM standard weight

Site No	ASTM Standard (lb/kg)	Actual Hammer Weight	Remark
Auto Trip 1	140 ± 2 lb/ 63.5 ± 0.91 kg	139.11 lb/ 63.10 kg	within the standard range
Auto Trip 2		139.33 lb/ 63.2 kg	
Auto Trip 3		140.54 lb/ 63.75 kg	
Auto Trip 4		136.69 lb/ 62.0 kg	3.31 lb less
Manual 1		139.11 lb/ 63.10kg	within the standard range
Manual 2		140 lb/ 63.50kg	
Manual 3		141.98 lb/ 64.4kg	
Manual 4		132.6 lb/ 60.16kg	7.4 lb less

An Auto Trip & a Manual hammer weight is found to be 136.69 lb & 132.6lb lbs. This is 3.31 lb & 7.41 lb less than the ASTM standard resulting in 2.36 % & 5.29% less energy transferred to the anvil per impact. As a result SPT N-value will be greater than that of actual value, hence over estimation of soil's strength.

4.3 Dimension of the Split-Spoon Sampler

In this study, levels were measured in eight split spoons from eight different sites. And actual value obtained from field is compared with ASTM standard. According to ASTM standards, split-spun samplers have a length of 457 to 762 mm (18 to 30 in), an inside diameter of 38.1 ± 1.3 mm (1.50 ± 0.05 in) and an outside diameter of 50.8 ± 1.3 mm (2.00 ± 0.05 in). Should be if the standard dimensions of the split-barrel sampler are more or less. The resulting SPT N value may be lower or higher than the ideal SPT N value. At two of the eight sites, the inner surface of the split barrel sampler was found to be unevenly opaque due to rust and corrosion. And the inner surface of the six sites appears transparent and smooth. As a result, the recorded penetration resistance is found to be equal to or less than the actual resistance. Below are the results obtained in this study and compared to the ASTM standard. Detailed information and differences are shown below Table 4.2

Table 4. 2: Comparison of Split-Spoon Sampler Data with to the ASTM Standard

Site No	ASTM Standard	Length	Remark	Inner Diameter	Remark	Outer Diameter	Remark
Site 1	Length 457 to 762 mm (18 to 30 inch)	600 mm	within the standard range	37.86 mm	within the standard range	52.42 mm	1.62 mm larger
Site 2		605 mm		36.54 mm		52.02 mm	within the standard range
Site 3	Inner Diameter 38.1± 1.3mm (1.50± 0.05 inch)	615 mm		38.26 mm		52.62 mm	1.82 mm larger
Site 4		596 mm		37.95 mm		52.02 mm	within the standard range
Site 5		587 mm		32.83 mm	5.27 mm less	52.08 mm	
Site 6	Out Side Diameter 50.8± 1.3 mm (2 ± 0.05 inch)	607 mm		36.19 mm	within the standard range	50.66 mm	
Site 7		609 mm		38.96 mm		52.25 mm	1.45 mm larger
Site 8		610 mm		38.19 mm		51.80 mm	within the standard range

Split spoon sampler inner diameter for Site 4 was found 5.27 mm less than the ASTM standard. Also the outer diameter of the split spoon sampler for Site 1 & Site 7 were found 1.62 mm & 1.45 mm greater than the ASTM standard. As a result, degree of soil disturbance would increase and affect SPT N-value.

4.4 Dimension of the Driving Shoe

In this study, the dimensions of eight driving shoes from eight different sites were determined. And actual values obtained from eight fields are compared with ASTM values. According to ASTM standards, the thickness of the driving shoe was 2.54 ± 0.25 mm (0.10 ± 0.02 in), the inner diameter was 34.93 ± 0.13 mm (1.375 ± 0.005 in) and the length was 25 to 502 in.) The inner surface of the driving shoe had no rust. Driving shoes are available transparent and smooth. According to ASTM standards, driving shoes have slightly rounded edges. Detailed information and differences are shown below Table 4.3

Table 4. 3: Comparison of driving shoe data with the ASTM standard

Site No	ASTM Standard	Thickness	Remark	Inner Diameter	Remark	Length	Remark
Site1	Thickness 2.54 ± 0.25 mm (0.10 ± 0.02 inch) Inner diameter 34.93 ± 0.13mm (1.375 ± 0.005 inch) Length 25 to 50 mm (1 to 2 inch)	1.54 mm	1 mm less	35.76 mm	0.83 mm larger	56 mm	6 mm larger
Site 2		3.03 mm	0.49 mm larger	35.23 mm	0.3 mm larger	57 mm	7 mm larger
Site 3		2.54 mm	within the standard range	35.52 mm	0.59 mm larger	55 mm	5 mm larger
Site 4		2.64 mm		35.70 mm	0.77 mm larger	59 mm	9 mm larger
Site 5		2.74 mm		36.15 mm	1.22 mm larger	60 mm	10 mm larger
Site 6		3.16 mm	0.62 mm larger	35.02 mm	within the standard range	50 mm	within the standard range
Site 7		2.43 mm	within the standard range	34.83 mm		50 mm	
Site 8		3.83 mm	1.29 mm larger	34.79 mm		55 mm	5 mm larger

Table 3. 12: Comparison between Auto Trip & Manual Rig System Data

ITEMS	ASTM Standard	Manual 1	Manual 2	Manual 3	Manual 4	Auto Trip 1	Auto Trip 2	Auto Trip 3	Auto Trip 4
Hammer Weight	140 ± 2 lb	It is within the range	It is within the range	It is within the range	Less 7.4 lb	It is within the range	It is within the range	It is within the range	Less 3.31 lb
Driving Shoes Thickness	2.54 ± 0.25 mm	Less 1 mm	Large 0.49 mm	It is within the range	It is within the range	It is within the range	Large 0.62 mm	It is within the range	Large 1.29 mm
Driving Shoes Inner Diameter	34.93 ± 0.13mm	Large 0.83 mm	Large 0.3 mm	Large 0.59 mm	Large 0.77 mm	Large 1.22 mm	It is within the range	It is within the range	Less 1 mm
Driving Shoes Length	25 to 50 mm	Large 6 mm	Large 7 mm	Large 5 mm	Large 9 mm	Large 10 mm	It is within the range	It is within the range	Large 5 mm
Split Spoons Length	457 to 762 mm	It is within the range	It is within the range	It is within the range	It is within the range	It is within the range	It is within the range	It is within the range	It is within the range
Split Spoons Inner Diameter	38.1 ± 1.3 mm	It is within the range	Less 1.56 mm	It is within the range	It is within the range	Less 5.27 mm	It is within the range	It is within the range	It is within the range
Split Spoons Out Side Dia	50.8 ± 1.3 mm	Large 1.62 mm	It is within the range	Large 1.82 mm	It is within the range	It is within the range	It is within the range	Large 0.15 mm	It is within the range

The study found an accurate free falling height of 30 inches as per ASTM for auto trip. This will result in proper power transfer to the anvil. SPT N value is found correct. On the other hand manual hammer does not maintain 30 inch free falling height as per ASTM due to which anvil transfers more or less power. As a result the correct SPT N value is not obtained.

As well as the driving shoes in both, manual and auto trip, split spoon, the standard is found to be inconsistent in many respects compared to ASTM. For which the soil property can be overestimated as a result of which the foundation can fail, the structure can fail. Also, if the soil property is under estimated, the foundation design will not be economical.

A total of eight studies found three out of four manual hammers within the hammer weight range and one hammer weighing 7.4 lb less than the manual- 4 as a result 5.29 % less energy will be applied to the anvil per blow. As a result the SPT N value will be higher. One of the four auto trip hammers available is the auto trip 4 - 3.31 lb less, which results in 2.36% less energy transferred to the anvil resulting in an impact on the SPT N-value. According to ASTM the hammer weight should be 140 ± 2 lb.

As per ASTM the thickness of driving shoes should be 2.54 ± 0.25 mm. Out of the total eight studies, four driving shoe thicknesses were found to be within the range as per ASTM standards. And four driving shoe thicknesses of 1mm, 0.49 mm, 0.62 mm, 1.29 mm are available. Which affects the SPT N value.

According to ASTM the inside diameter of split spoon sampler should be 38.1 ± 1.3 mm. The outside diameter should be 50.8 mm as well as the length should be 457 to 762 mm but in five of the eight studies, six studies found the split spoon inside diameter range and 2 studies found 1.56 mm, 5.27 mm less. Split spoon outer diameter five studies out of a total of eight studies found split spoon outer diameter within the range. Three studies found 1.62 mm, 1.82 mm, and 0.15 mm more. SPT N-Value may be affected if split spoon is not maintained as per standard.

4.5 Free-Falling Height

The SPT auto hammer blow and free-falling height data recorded. For Manual 1 & 6 are given in Table 4.4 & 4.5 for one borehole (BH). A total of 443 & 40 hammer blows were recorded with a total of 443 & 40 blows released from a standard free-falling height of 30 inches, which is 100% of the total 443 & 40 blows released from a standard free-falling height of 30 inches hence accurate estimation of soil's strength.

Table 4. 4: No of hammer blows and free-falling data auto hammer 1

Free-falling Height (Inch)	No of Hammer Blow	Total	Percentage (%)
Standard height of 30 Inch	443	443	100%

Table 4. 5: No of hammer blows and free-falling data site auto hammer 6

Free-falling Height (Inch)	No of Hammer Blow	Total	Percentage (%)
Standard height of 30 Inch	40	40	100%

For Site 2 SPT hammer blow and free-falling height data recorded at slow motion are given in Table 4.6 for one borehole (BH). A total of 380 hammer blows were recorded with only 179 blows released from the standard free-falling height of 30 inch, which is 47.1% of the total blows. 104 blows were released from heights greater than the standard free-falling height of 30 inch, which is 27.4% of the total blows. 97 blows were released from heights less than the standard free-falling height of 30 inch, which is 25.5% of the total blows. Most of the blows were released from a standard free-falling height of 30 inch. Which is accountable for the transmission of equal energy to the sampler, hence it is within the range estimation of soil's resistance.

Table 4. 6: No of hammer blows and free-falling data manual site 2

Free-falling Height (Inch)	No of Hammer Blow	Total	Percentage (%)
Standard height of 30 Inch	179		41.1%
From higher than 30 (inch)	104	380	27.4%
From lower than 30 (inch)	97		25.5%

For site 3 recorded SPT hammer blow and free-falling height data are given in Table 4.7 for one borehole (BH). A total of 556 hammer blows were recorded while only 176 were released from the standard free-falling height of 30 inch, which is 30.9 % of the total blows. 192 blows were released from heights greater than the standard free-falling height of 30 inch, which is 33.7% of the total blows. 201 blows were released from heights less than the standard free-falling height of 30 inch, which is 35.3% of the total blows. Most of the blows were released from heights less than the standard free-falling height. Which is accountable for the transmission of lower energy to the sampler, hence over estimation of soil's resistance

Table 4. 7: No of hammer blows and free-falling data manual site 3

Free-falling Height (Inch)	No of Hammer Blow	Total	Percentage (%)
Standard height of 30 Inch	176		30.9%
From higher than 30 (inch)	192	569	33.7%
From lower than 30 (inch)	201		35.3%

For site 4 SPT hammer blow and free-falling height data recorded at slow motion are given in Table 4.8 for one borehole (BH). A total of 224 hammer blows were recorded with only 93 blows released from the standard free-falling height of 30 inch, which is 41.5% of the total blows. 74 blows were released from height greater than the standard free-falling height of 30 inch, which is 33.04 % of the total blow. 57 blows were released from height less than the standard free-falling height of 30 inch, which is 25.4% of the total blows. Most of the blows were released from a standard free-falling height of 30 inch. Which is accountable for the transmission of equal energy to the sampler, hence it is within the range estimation of soil's resistance.

Table 4. 8: No of hammer blows and free-falling data site 4

Free-falling Height (Inch)	No of Hammer Blow	Total	Percentage (%)
Standard height of 30 Inch	93	224	41.5%
From higher than 30 (inch)	74		33.04%
From lower than 30 (inch)	57		25.4%

For site 5 recorded SPT hammer blow and free-falling height data are given in Table 4.9 for one borehole (BH). A total of 79 hammer blows were recorded while only 20 were released from the standard free-falling height of 30 inches, which is 25.3% of the total blows. 20 blows were released from heights greater than the standard free-falling height of 30 inches, which is 25.3% of the total blows. 39 blows were released from heights less than the standard free-falling height of 30 inch, which is 49.4% of the total blows. Most of the blows were released from heights less than the standard free-falling height. Which is accountable for the transmission of lower energy to the sampler, hence over estimation of soil's resistance.

Table 4. 9: No of hammer blows and free-falling data manual site 5

Free-falling Height (Inch)	No of Hammer Blow	Total	Percentage (%)
Standard height of 30 Inch	20	79	25.3%
From higher than 30 (inch)	20		25.3%
From lower than 30 (inch)	39		49.4%

4.6 Energy Efficiency

The theoretical and practicing SPT hammer energy efficiency with depth and SPT N value are shown in Table 4.9 from the table we can understand that some practicing hammer energy efficiency is less than theoretical energy efficiency again some practical hammer energy efficiency is higher than theoretical energy efficiency are shown in Figure 4.1 and Figure 4.2 and respectively. From the figures it is clearly seen that the practiced hammer energy efficiency compares to the theoretical energy efficiency.

Table 4. 10: Practicing energy efficiency data of six sites

Site No	Hammer Type	Theoretical Energy Efficiency	Practicing Energy Efficiency
Site 1	Auto Trip	100%	99.4 %
Site 2	Manual		96.1% to 105.3 %
Site 3	Manual		89.4% to 103.7 %
Site 4	Manual		99.7% to 104.3%
Site 5	Manual		95.5% to 113.7%
Site 6	Auto Trip		99.5%

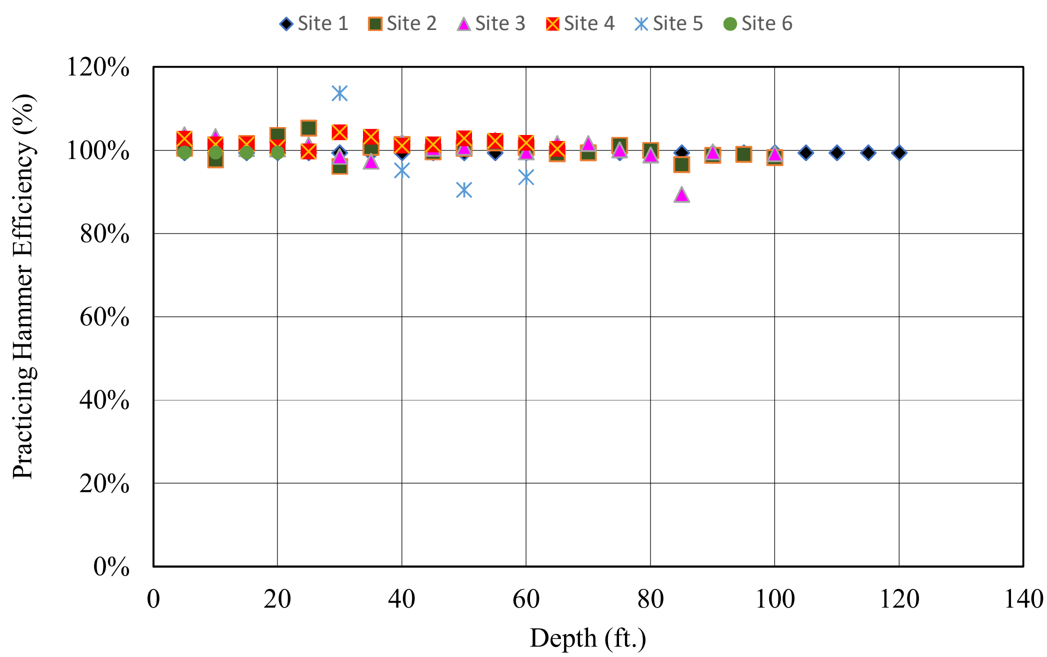

Figure 4. 1: Practicing energy efficiency of SPT hammer with depth

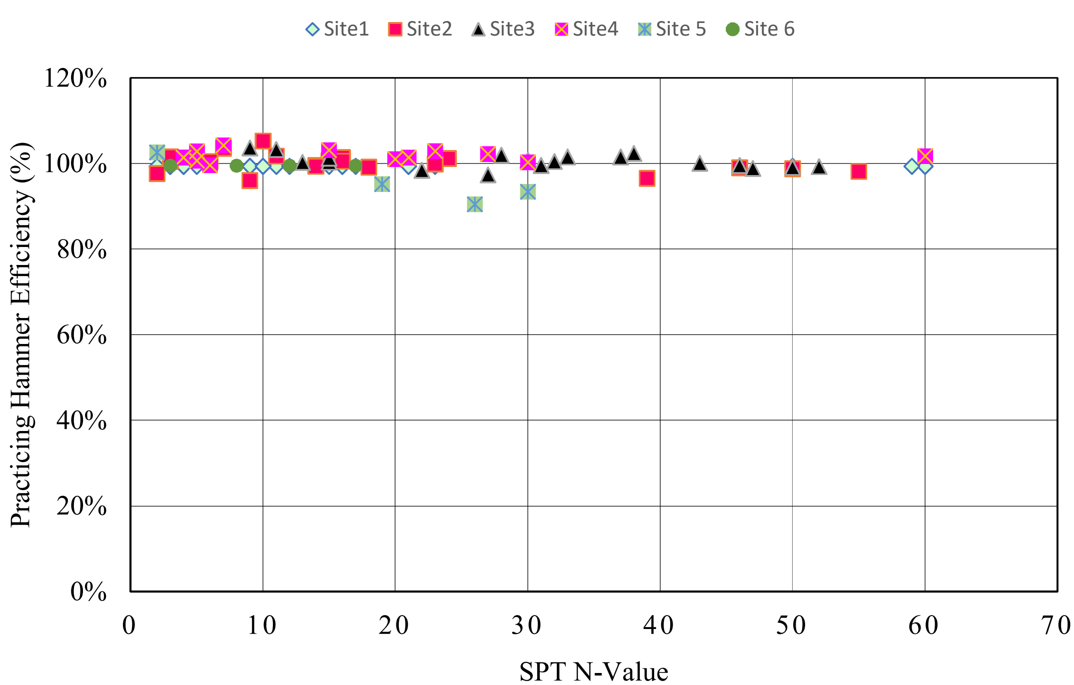

Figure 4. 2: Practicing energy efficiency of SPT hammer with SPT N- value

CHAPTER FIVE
CONCLUSION AND RECOMMENDATION

5.1 General

In this study, SPT hammer weight, split-spoon sampler dimensions, driving shoe dimension, free-falling height and energy efficiency data are collected from manually and auto hammer operated SPT rigs and the data are compared with ASTM standards. This chapter summarizes the conclusions drawn from this study, limitations of the study, and recommendations for future research.

5.2 Conclusion

The main objective of this study is to compare SPT with ASTM standards for eight different sites in terms of hammer weight, split-spoon sampler dimensions, driving shoe dimension, free-falling height and energy efficiency. The following conclusions can be drawn from the present study-

i The study is done by four auto trip hammer and four Manual rig operators and according to ASTM, the difference between auto trip and manual work is determined. For the research mainly 6 sites and 2 firms were visited to collect data. The study shows that according to ASTM the free falling height of auto hammer is maintained at 30 inches but manual hammer standards 30 inch height is not maintained.

ii Of the eight hammers practiced, four were auto trip hammers and four were manual hammers. Available in six hammer weight ranges. And the two hammer weights are found to be 132.6 lb & 136.69 lb. But according to ASTM standards the hammer weight should be 140 ±2 pounds. Hence the practice hammer weight is 7.4 lb & 3.31 lb less than the standard weight. Which causes 5.29 % & 2.36 % power reduction per blow.

iii Of the eight driving shoe thicknesses practiced, three driving shoe thicknesses are large, one driving shoe thickness is less, and four driving shoe thicknesses are found to be in the range. As per ASTM the thickness of driving shoes should be 2.54 ± 0.25 mm.

iv Of the eight split spoon samplers used in the test, two spoons were found to have less inside diameters. Inside diameters of six spoons were found to be within the range. Inner diameter should be 38.1 ± 1.3 mm as per ASTM.

v Of the eight sites tested, four sites were found to be within the range of free falling elevations. Because there are automatic trip hammers used. And the free-falling height of the manual hammer at four locations is measured by high-definition video recording. Reference lines were marked 3 inches above and below the standard 30-inch height to measure the correct free-falling height.

vi Practice has also found that the energy efficiency of the auto hammer falls between 99.4 % to 99.5 %. Also the energy efficiency of the donut hammer falls between 89.4 % to 113.7 %.

5.3 Limitations

The limitations of the study: -

i Energy loss due to the friction between rope and pulley, and donut surface of the hammer and guide pipe were not consider in the computation of practicing energy efficiency.

ii Estimated practicing energy may not reflect the actual energy transfer to the SPT sampler.

iii Hammer weights could not be measured with digital weighing machines at two sites of the eight sites.

5.4 Recommendations

The following recommendations for further studies can be made –

i. Sophisticated pile driving analyzer (PDA) maybe used to determine the actual energy of drop and energy transfer to the sampler for comparing the results of this study.

REFERENCE

[1] A. H. S. A. M. A. A. Md. Mahbubur Rahman, "STANDARD PENETRATION TEST: STANDARD VERSUS PRACTICE IN BANGLADESH," *STANDARD PENETRATION TEST,* pp. 1-37, 2021.

[2] M. Z. A. Debojit Sarker, "Applicability of Standard Penetration Test in Bangladesh and Graphical Representation of SPT-N Value," *Science and Engineering Investigations,* vol. 4, no. 41, pp. 55-58, 2017.

[3] M. S. HOSSAIN, "EFFECTS OF DROP ENERGY ON SPT VALUE OF SOIL IN BANGLADESH CONTEXT," pp. 1-137, 2006.

[4] J. D. ROGERS, "Subsurface Exploration Using the Standard Penetration," *the geological society of america,* p. 161–179, 2006.

[5] S. S. E. K. S. S. A. S. Nahesson P1, "Distribution pattern of soil bearing capacity on the island of," *Conference Series,* pp. 1-7, 2021.

[6] M. S. A. A. W. R. RADDING, "STANDARD PENETRATION TEST (SPT) CORRECTION," pp. 1-93, 2001.

[7] Z. A. Urmi, "GEOTECHNICAL CHARACTERIZATION OF RIVERINE AND COASTAL EMBANKMENT SOIL OF BANGLADESH BASED ON CONE PENETRATION TESTING AND STANDARD PENETRATION TESTING," pp. 1-433, 2019.

[8] R. HORE, "LIQUEFACTION POTENTIAL OF SELECTED RECLAIMED AREAS OF DHAKA CITY BASED ON CONE PENETRATION TEST," pp. 1-188, 2013.

[9] N. R. Shaha, "Relationship between Penetration Resistance and Strength-Compressibility Characteristics of Soil," pp. 1-116, 2013.

[10] A. K. Reza Ziaie Moayad, "Evaluation of Iranian Standard for Assessment of Liquefaction Potential of Cohesionless Soils Based on Standard Penetration Test," vol. 15, pp. 1-4, 2021.