EFFECTS OF DROP ENERGY ON SPT VALUE OF SOIL IN BANGLADESH CONTEXT

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DHAKA 1000, BANGLADESH

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The thesis titled "Effects of Drop Energy on SPT Value of Soil in Bangladesh Context", Submitted by Md. Shakhawat Hossain, Student ID no.-0409042221, Session: April' 2009; has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Engineering in Geotechnical Engineering on June, 2016.

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DECLARATION

It is hereby declared that, except where specific references are made, the work embodied in this thesis is the result of investigation carried out by the author under the supervision of Dr. Md. Zoynul Abedin, Professor, Department of Civil Engineering, BUET.

Neither this thesis nor any part of it is concurrently submitted to any other institution in candidature for any degree.

Md. Shakhawat Hossain

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ABSTRACT

Standard Penetration Test (SPT) is the most popular subsurface investigation test for foundation design in Bangladesh as well as in the whole world. Unfortunately the SPT values are not unquestionable in Bangladesh because of non-standard parameters that are being in practice here. There are numerous factors considered by ASTM that effect the value of SPT. Some of these factors include the drill stem length and cross section the type of anvil, the blow rate, the technique of operation, the alignment and type of hammer, the use of liners or borehole fluid etc. Of all of the documented variables the hammer type is perhaps the most significant parameter due to its variability in energy delivered to the drill rods. Researchers have shown that energy transfer efficiency can be 30% to 90% depending on the type of hammer used.

In Bangladesh, majority of the SPT is done manually. A hammer is attached with a rope. The workers pull the rope and lift the hammer by 30 inch or so and release it. The hammer hits the drilling rod and the attached split spoon sampler is penetrated. Human error is involved in this system. Moreover, number of turns in the pulley varies from site to site. Thus SPT remains in a very nonstandard form in Bangladesh. No previous study is reported to find the efficiency of energy transfer of these systems that are being used in Bangladesh. In very few cases use of auto trip hammer has been reported.

In this study SPT Analyzer was used with PDA Machine to observe the efficiency of the hammer system. Two feet long NW-1 drill rod section, hand-held unit and the software for evaluating the data were used. Foil strain gauges were glued directly onto the rod to measure strain, which was converted to force by using the cross sectional area and modules of elasticity of the rod. The acceleration measured by the accelerometer was integrated to obtain velocity. The instrumented rod was affixed to the top of the drill string just below the anvil during testing.

Standard Penetration Tests were conducted in three selected locations of Dhaka city, using both by Manual and Auto trip hammer. The sites were Rajarbag Police Line, Dhaka, Sarkari Shishu Paribar, Tejgaon and Business studies faculty, Dhaka University. The test data showed that the energy transfer ratio (ETR) in automatic hammer was around 40-70% that might be considered within the range of standard 60% efficiency. The ETR in manual hammers were found to be around 33-66% and the range was found inclusive of standard 60% efficiency. In case of auto trip hammer, ETR was found inversely proportional to SPT which was indicated by ASTM D4633-05.In case of manual hammer ETR was found directly proportional to SPT. As expected, better consistency of ETR was observed for auto trip hammer as compared to manual hammers.

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Chapter 1
INTRODUCTION

1.1 General

The Standard Penetration Test, known as the SPT, is commonly used for subsurface investigations for foundation and geotechnical designs. It is one of the most broadly used tests world-wide to characterize in-situ soil strength. While other in-situ tests are available, CPT, CPTU and dilatometer to mention a few, only the SPT test enables the drill crew to retrieve soil samples. The SPT test is made by dropping a free-falling hammer weighing 140 lb onto the drill rods from a height of 30 inches to achieve the penetration of a standard sample tube 18 inches into the soil. The number of blows required to penetrate each 6-inch increment is recorded and the number of blows required to penetrate the last foot is summed together and recorded as the N value. The first 6 inches of penetration tends to reflect disturbed material remaining in the hole from the removal of the drill and insertion of the sampler, therefore the blows corresponding to the first 6 inches of penetration are recorded but are not ordinarily included in the N value.

One advantage of the SPT is that the drillers can collect samples for further classification and laboratory testing. Another advantage of this simple and economical test is the significant body of research that has been done to correlate empirically the SPT N values with geotechnical design parameters such as soil density, consistency, friction angles, undrained shear strength, Young's modulus, shear modulus, settlement of shallow and deep foundations in sand bearing capacity values, and to provide an index of soil liquefaction resistance. Thus the N value saves money by reducing laboratory testing. Unfortunately, the SPT values are questionable because of non-standard parameters inherent in the method.

The SPT is subject to a large number of variables that affect the results of the test. There are numerous factors permitted by ASTM that effect the N value. Some of these factors include the drill stem length and cross section, the type of anvil, the blow rate, the technique of the operator, the alignment of the hammer, the use of liners or bore hole fluid and the type of hammer. Of all of the documented variables the hammer type is the most influential due to the variability in energy delivered to the drill rods. Researchers have shown that energy transfer efficiency can be in between 30% to 90% depending on the type of hammer used. Thus, different drill rig hammer systems give different N values for the same site. It has been

found that an inverse relationship exists between the N measured and the efficiency of the hammer. In the context of Bangladesh, no previously known research has been conducted to measure the efficiency of energy transfer during SPT. Majority of the SPT done in Bangladesh is manually operated when a very few auto trip hammers are available. It is common practice in Bangladesh to make important decisions based on available correlations of different soil properties with SPT. As said earlier, these correlations are made with standard SPT values. For this reason, it is very important to know the efficiency of equipment and method used in this country. This research aims to investigate the efficiency of equipment used commonly in Bangladesh.

1.2 Background and Present State of the Problem

The Standard Penetration Test (SPT), developed during late 1920's, is now the most popular and economic method of sub surface sampling for geotechnical exploration. Inconsistence within the testing procedure itself such as variations in hammer types and operation variables can have a large effect on the result of the test (Bowles, 1997) and hammer blow rates Sherif and Radding (2001).

Many of the SPT correlations have been explored, and there exists no small number of problems, requiring considerable judgment. Most of these problems are discussed by Flecher (1965), Ireland et. al. (1970), De Mello (1971) and Lacroix & Horn (1973). In 1986 a series of new correlations and corrections were introduced, which are in current usuage (i.e. Riggs, 1986; Skempton, 1986; Liao & Whitman, 1986). Clayton (1990); Youd, Bartholomew, Hannah and Jamison (2008) presented an expanded listing of SPT hammer efficiencies.

Despite of all these corrections, SPT data can be corrected for a number of site specific factors to improve its repeatability, specially the hammer efficiency. From the several recent studies, it has been suggested that the SPT be standardized to some energy ratio as given by:

$$Energy\ ration, E_r = \frac{Actual\ hammer\ energy\ to\ sampler}{Input\ energy, E_{in}} \times 100$$

Energy correction concept was first introduced by Burmister (1948). He suggested a simple input energy correction for the ratio of driving weight (hammer energy) versus sample diameter. Since then significant research has been done on the energy issue considering site specific factors. Unfortunately, researches on SPT in context of Bangladesh site factors are very limited.

1.3 Present Status of SPT in Bangladesh

At present SPT is the most common and vastly used soil investigation technique used in Bangladesh. Most of the drill crew members are not trained and the authenticity of SPT blow record is often questionable. The uniformity of hammer system available in the country is also in doubt. Most of the hammers are manually operated. Only a few auto trip hammers are available which are used in more important projects. SPT value obtained is inversely proportionate with the energy transfer onto the drill rod from the hammer. No such study has been carried out in the country to estimate the energy transfer from these equipment.

Practicing engineers often have to rely solely on the SPT values to reach design conclusion which can be dangerous without proper knowledge of the energy transfer through these machines.

1.4 Objectives of the Study

The main objectives of present study are as follows:

i) To determine the energy transferred from the hammer to the drill rod by using sophisticated PDA analyzer.
ii) To determine the energy of drop for various site and soil conditions.
iii) To get relationship of 'N' Value by estimating the energy transfer.

It is expected that from this research the following outcome(s) will be obtained:

i) The energy which passed into the drill rods can be determined from the force and velocity of hammer.
ii) The hammer energy ratio, E_r is then calculated taking into account the mass of the hammer and the falling height with the actual drive energy, E_{in}
iii) The energy ratio may be estimated for both conventional drop hammer and automatic trip hammer and make relationship with actual hammer energy.

1.5 Outline of Methodology and Experimental Plan

A series of SPT hammer energy measurements on a number of hammers using the pile driving analyzer (PDA) as suggested by Abou-matar and Goble (1997) would be done. The SPT analyzer would be furnished with a 0.6m sub assembly or section of an SPT rod

instrumented with 2 strain gauge bridges and precisely calibrated by pile dynamics. Two accelerometers are to be bolted to the rod section. The instrumented section would be inserted at the top of the drill string between the hammer and existing sampling rods. The rod would be connected to the SPT analyzer. The strain gauges and accelerometers would obtain the force and velocity signals necessary for the calculation of transferred energy during the normal course of the SPT test from which actual hammer energy can be found out and different relationship of energy transfer would be obtained.

Chapter 2
LITERATURE REVIEW

2.1 General

Two very thorough treatments of the history of Standard Penetration Test have been published. Broms and Flodin (1988) discuss the "History of Soil Penetration Testing" from ancient times through the 1980's. The University of Florida report by Davidson, Maultsby and Spoor (1999), details the history of SPT testing and the ASTM standardization of SPT testing from the beginning of the 20th century through the present. According to this report the earliest credits for the SPT are attributed to Mohr and also to Terzaghi. Hvorsolv credits Mohr for developing the test in 1927 and the SPT Working Party credits Terzaghi for the SPT. Reference can be made to Davidson, Maultsby and Spoor (1999). Broms and Flodin (1988) also reports on more information on the history. In the following Sections literature related to various aspects of Standard Penetration Test is presented in Section 2.2.

2.2 A Chronological History of the Development of Standard Penetration Test

Though many authors published literature on the history of Standard Penetration Test (SPT), the one presented by Rogers (2006) may be considered a useful chronological review of the SPT history, and reproduced as under this Section and in the Sub-Sections.

In 1902, Charles R. Gow, owner of the Gow Construction Co. in Boston, began making exploratory borings using 1 in. (2.5 cm) diameter drive samplers driven by repeated blows of a 110 1b hammer to aid in estimating the cost of hand excavating belled caissons (Fletcher, 1965; Mohr, 1966). The dimensions and layout of this device are shown in Figure 1(a). Until that time, contractors used wash borings with cuttings, similar to the methods presently used in advancing water wells. In 1922, Gow was absorbed as a subsidiary of the Raymond Concrete Pile Co. (RCPC) under the direction of Linton Hart (Fletcher, 1965). The Gow Division of RCPC continued to employ the pipe sampler, which was hand powered and operated by three-man crews. The split-spoon soil sampler was introduced by Sprague and Henwood, Inc., of Scranton, PA, in the mid-1920s and marketed nationally. It was manufactured in variety of sizes, with outside diameters of 2.0 in. (5.1 cm), 2.5 in. (6.35 cm), 3.0 in. (7.6 cm), and 3.5 in. (8.9 cm). The inside diameters of these samplers were 0.50 in. (1.27 cm) less than the outer dimensions cited above. Two-inch (5-cm)-diameter split-spoon

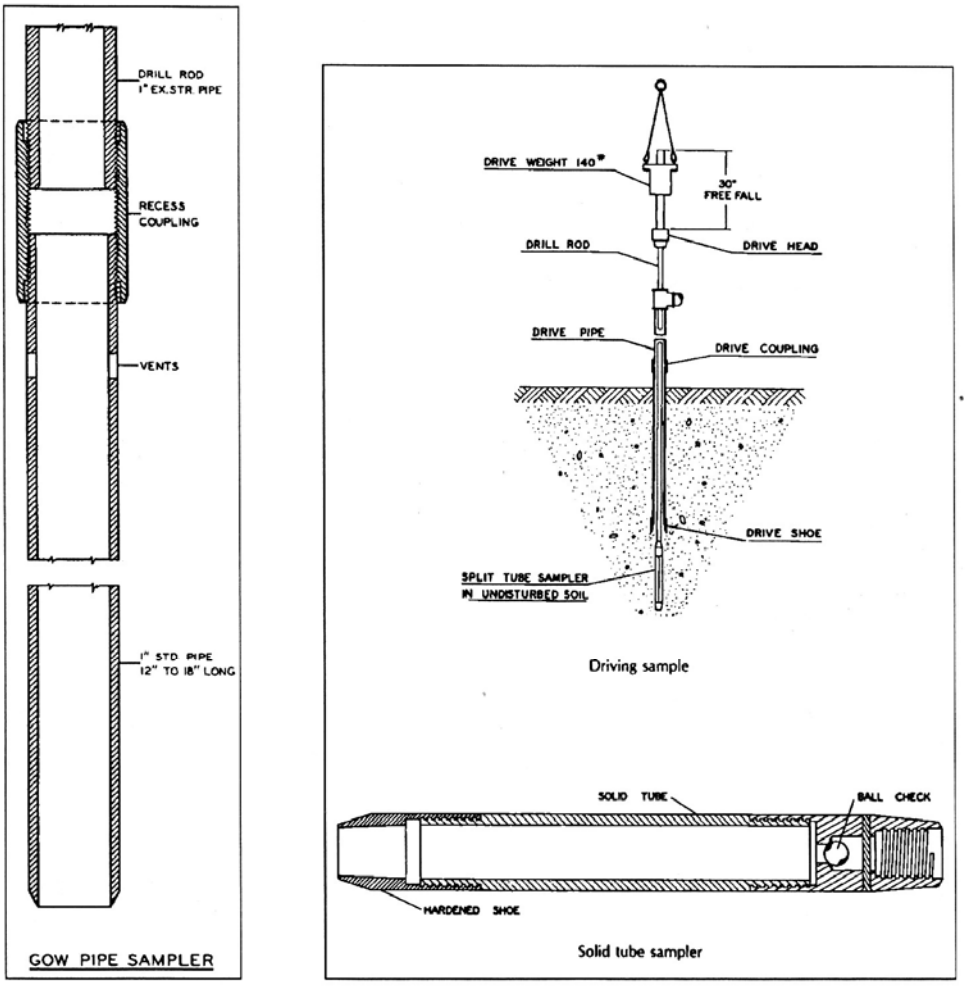
sampler was introduced in 1927 through the cooperative efforts of three Gow engineers: Linton Hart in New York, Harry Mohr in Boston, and Gordon Fletcher in Philadelphia. During this same period (late 1920s), Harry Mohr measured the numerical values of driving force employed by Boston area drilling crews, determined to be 140 lbs (69.3 kg) average driving weight with an average 30 in. (76.2 cm) drop, recording the number of blows required to drive the sampler 12 in. (30.5 cm) (Fletcher, 1965; Mohr, 1966). Other firms used a variety of split-spoon and push tube samplers with outside diameters varying between 2.0 and 4.5 in. (5 and 12.7 cm) and hammer weights between100 and 350 lbs (45.5 and 159 kg) (Mohr, 1936, 1943; Stanton, 1936; and Acker, 1974).

This modified Gow sampler recovered $1\frac{3}{8}$ in (3.5 cm) diameter samples. Even though disturbed, drive samples were able to recover thin seams of material in the correct stratigraphic sequence, providing important details that wash borings could not. Improvements to the sample barrel were made over the years, including the introduction of a ball check valve to prevent sample loss. In 1945, the split-spoon sampler barrel was augmented by the introduction of size A hollow drill rods [wall thickness of 0.234 in. (0.59 cm)], which were equipped with Jackbit threads (coarse flat threads, without deep or sharp undercuts). These replaced the old 1-in. extra pipe that had been used until that time (Fletcher, 1965). By 1940, the Gow split-spoon sampler essentially appeared as we know it today but accommodated only a 12 in. (30.5 cm) long sample, as shown in Figure 1(b).

During the early1940s, RCPC lengthened their sampler to accommodate 22 in. (55.9 cm) of sample, and this apparatus became known as Raymond Sampler (Hvorslev, 1949). In 1954, James D. Parsons of Moran, Proctor, Freeman, and Mueser in New York introduced the conventional procedure wherein blows are recorded for each of three 6-in. (15.2-cm) increments (Fletcher, 1965). The value recorded for the first round of advance is usually discarded because of fall-in and contamination in the borehole (Lo Pinto, 1966). The second pair of numbers are then combined and reported as a single value for the last 12 in. (30.5 cm). This value is reported as the raw (uncorrected) Standard Penetration Test (SPT) blow-count value, commonly termed N or, more recently, as N_{SPT}.

Terzaghi realized that the penetration resistance of the split-spoon sampler could provide useful in situ test data that might be correlated with the consistency and density of the soils encountered. While he was writing the text of Soil Mechanics in Engineering Practice, lie sat

down with Harry Mohr and developed correlations between the number of blows, N, and a number of salient properties of soils, including the relative density of sands, consistency and unconfined compressive strength of clays, and allowable bearing pressure on sands and clays.



(a) (b)

Figure 2.1: (a) Original Gow 1 in diameter pipe sampler; (b) Components of a 2 in diameter SPT split spoon sampler developed around 1927(after Rogers, 2006)

In 1947, Terzaghi christened the Raymond Sampler procedure as the "Standard Penetration Test" (SPT) in a presentation titled "Recent Trends in Subsoil Exploration," which he gave at the 7th Conference on Soil Mechanics and Foundation Engineering at the University of Texas at Austin. The first published SPT correlations appeared in Terzaghi and Peck (1948). These were soon followed by correlations relating SPT blow counts to consistency for silts and clays and relative density for sands in Peck et al. (1953), who noted that the data for sands were more reliable than those for silts or clays. These classification charts are shown in Table

2.1. The SPT procedure and its simple correlations quickly became soil classification standards across the United States. By 1960, published charts were appearing that also estimated soil strength based on SPT blow counts, presented in Table 2.2.

Table 2.1: Prior to the introduction of energy correction for depth, uncorrected blow counts, N_{SPT} were compared with charts like those reproduced here from Rogers (2006). These correlations were used in classifying soils and used to determine allowable bearing capacity and friction parameters for soils.

Relative Density		Consistency		
Sands and Gravels	Blows/ft (N_{SPT})	Silts and Clays	Strength (tsf)	Blows/ft (N_{SPT})
Very loose	0 - 4	Very soft	0 – 0.25	0 - 2
Loose	4 - 10	Soft	0.25 – 0.50	2 - 4
Medium	10 - 30	Firm	0.50 – 1.0	4 - 8
Dense	30 - 50	Stiff	1 - 2	8 - 16
Very dense	Over 50	Very stiff	2 - 4	16 - 32
		Hard	Over 4	Over 32

Table 2.2: Estimated values of soil friction and cohesion based on uncorrected SPT blow counts. Although bereft of overburden corrections, these simple correlations were generally used for shallow foundation investigations.

Soil Type	SPT Blow Count	Undisturbed Soil	
		Cohesion (psf)	Friction Angle (^{o})
Cohesive soils:			
Very soft	< 2	250	0
Soft	2 - 4	250 - 500	0
Firm	4 - 8	500 - 1000	0
Stiff	8 - 15	1000 - 2000	0
Very stiff	15 - 30	2000 - 4000	0
Hard	> 30	4000	0
Cohesionless soils:			
Loose	< 10	0	28
Medium	10 - 30	0	28 - 30
Dense	> 30	0	32
Intermediate soils:			
Loose	< 10	100	8
Medium	10 - 30	100 - 1000	8 - 12
Dense	> 30	1000	12

The "standard drive sampler" test was subsequently adopted by ASCE and the Corps of Engineers. In the early 1950s, Sprague and Henwood began producing an 18-in. (45.7 cm)

version of the 22 in. (55.9 cm) Raymond Sampler, and the barrel length was left open ended (between 18 and 30 in. [45.7 and 76.2 cm] when the SPT was adopted as ASTM Standard D 1586-84 in 1958 (Figure 2.2). Since this time, it has more or less become a nationwide standard. Despite standardized barrel dimensions, SPT samplers still employ an array of cutting shoes with varying tapers and lip widths. Variations on the SPT procedure have been adopted by many countries, and the International Reference Test Procedure for the SPT was adopted by the International Society for Soil Mechanics and Foundation Engineering in 1988.

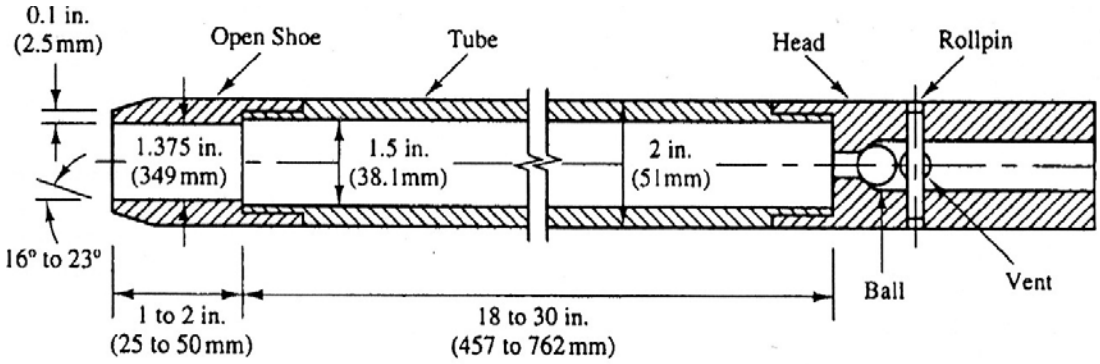


Figure 2.2: Standard dimensions for the ASTM D1586 SPT sampler

2.2.1 Disadvantages of the SPT Procedure

According to Rogers (2006), the SPT procedure evolved out of the Boston area, where Charles Gow used it to probe conditions preparatory to constructing his Gow Caissons, as was custom elsewhere (Mohr, 1964). The procedure is most reliable in granular soils, such as sand and granule gravel. A major shortcoming with the SPT has been that silts and clays exhibit different driving resistances when dry or moist. If these materials become more moist at a later date, they may not exhibit the stiffness predicted by the SPT.

Another common source of interpretive error in the SPT procedure is when the sampler encounters rocks slightly larger than the sample barrel's sleeve diameter. In these cases, very high blow counts can be recorded, and these horizons can easily be misinterpreted to be "bedrock" or "drilling refusal" when, in fact, the object may be a "floater" within the colluvium. Seasoned operators usually take their boringsa good 10 ft(3 m) into supposed "rock" to be sure of the interpretation, usually through drilling resistance, not according to drive sampling resistance alone.

A less recognized problem is the influence of strata thickness and changes in stiffness. As the sample barrel approaches an appreciably stiffer horizon, the penetration resistance will

increase, even though the sampled material remains more or less constant throughout the softer horizon. This can lead to overestimates of strength, density, and compressibility based solely on blow-count values. A big disadvantage of the SPT procedure is that it reports the average blows per foot during any given sample round, so the measurement would only be valid for horizons > 12 in. (30.5 cm) thick, plus the influence area beneath the sampler shoe. This is the zone of influence in front of the sampler shoe. This influence zone usually encompasses an additional 8-14 in. (20-36 cm), equal to four to seven times the sample barrel diameter. Overall, the SPT procedure tends to "average" the penetration resistance of the materials sampled, and the material effects of low strength horizons less than 20 to 26 in. (51 to 66 cm) thick may altogether be missed, though their existence may be gleaned from visual inspection of the recovered samples.

2.2.2 Baseline References on the SPT Procedure

Many of the SPT correlations have been explored, and there exists no small number of problems, requiring considerable judgment. Most of these problems are discussed in the following publications: Fletcher (1965), Ireland et al. (1970), de Mello (1971), LaCroix and Horn (1973), Liao and Whitman (1986), Skempton (1986), Clayton (1990), Robertson and Wride (1997), and Youd and Idriss (1997).

In 1986, a series of new correlations and corrections were introduced, and these are in current usage. These included Liao and Whitman (1986), Riggs (1986), Skempton (1986), and Robertson and Wride (1997). In 1990, Clayton (1990) presented an expanded listing of SPT hammer efficiencies (E) and rod energy ratios (CE) that have been widely accepted and were reproduced in Clayton et al. (1995). For evaluation of liquefaction potential, raw SPT blow counts are normally corrected to $(N_1)_{60}$ values, described later.

2.2.3 Burmister's Input Energy Correction

Despite all the encouragement to adopt Terzaghi's SPT, most people went on using whatever devices they had previously until more and more of Casagrande's students infiltrated the ranks of foundation engineering. In the New York area, the favored device was the 3.625-in.-diameter Moran & Proctor or, M & P Sampler, which had been developed by Carlton Proctor for the firm's exploration of the San Francisco Bay Bridge project (Proctor, 1936). The M & P sampler(Figure 2.3) allowed recovery of much larger 3 in (7.6 cm) diameter samples, using 5,000 in.-lbs (5,760 cm-kg) per blow in lieu of the SPT's 4,200 in.-lbs (4,838 cm-kg). Proctor

engaged Professor Donald Burmister of Columbia University to develop a scheme for correlating M & P sampler blow counts with those of Mohr's smaller SPT sampler, commonly employed in New England. Burmister assumed that SPT blow counts were simply proportional to driving weight and energy input versus the annular cross-sectional area of the sampler shoe. This reasoning ignored the increase in skin friction area with larger-diameter samplers and increasing skin friction with depth.

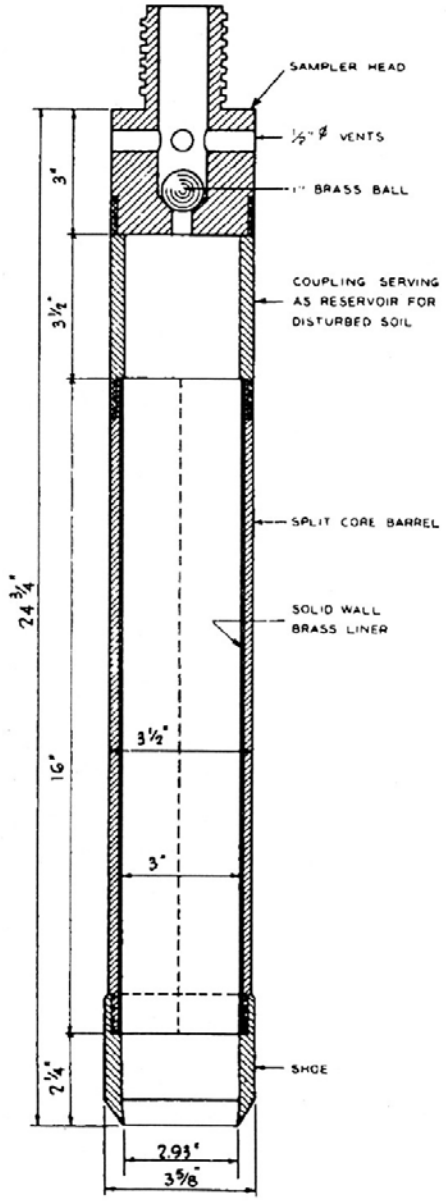


Figure 2.3: M and P drive sampler developed Morgan and Proctor in early 1930s

Burmister's relationship considered energy input as the weight of hammer multiplied by drop height, the size of the recovered sample (D_i), and sample barrel diameter (D_o). These factors

were combined to provide input energy and diameter correction for other tests to correlate with the same values used in the SPT procedure (ASTM, 1984, D 1586-84) as

$$N^* = N_R \frac{(W\ lbs)(H\ in)}{(140\ lbs)(30\ in)} \left[\frac{(2\ in)^2 - (1.375\ in)^2}{(D_o)^2 - (D_i)^2}\right] \qquad (2.1)$$

Where,W is the hammer weight, H is the height of the drop, D. is the outside diameter of the sample barrel, D_i is the diameter of the drive sample, N_R is the raw blow count, and N* is the blow count reported as the equivalent SPT value. The Burmister energy correction takes the raw SPT blow-count value and multiplies it by an appropriate fraction, derived from this relationship. The corrected blow-count value is usually denoted by an asterisk (*) on the boring log, with a note explaining that the blow counts have been adjusted.

Like New York, California has long employed the SPT method along with employment of a larger-diameter drive sampler that uses brass rings or 6-in. (15.2-cm)-long brass liners inside the sample barrel to allow easy removal of soil samples back to the lab, where they can be extruded and evaluated. California routinely employs two different sized samplers, both called "Modified California," or "Mod Cal," samplers. The smaller version has a D. = 2.5 in. (6.35 cm) with Di = 1.875 in. (4.76 cm) with brass liners. The larger version employs a D_o = 3.0 in. (7.62 cm) with D_i = 2.4 in. (6.1 cm).

If Burmister's energy-area equation is applied to the larger Mod Cal sample barrel, with Do = 3.0 in. and Di = 2.4 in., the correction would be 0.65. The correction for the smaller Mod Cal barrel would be 0.77. This means that the "equivalent SPT N values" would be about 6577 percent of those recorded with either of the Mod Cal samplers. This energy correction does not make a distinction between cohesive (i.e., clay) and non-cohesive (i.e., sands and gravels) materials, which should affect the side friction of the sample barrel markedly. Nevertheless, there existed nothing better, so most professionals cited Burmister's 1948 "correction" for adjusted blow counts recorded with larger-diameter drive samplers or for lower-energy hammers (de Mello, 1971).

2.2.4 Lacroix and Horn (1973) Correction

In 1973, Yves Lacroix and Harry Horn of Woodward-Clyde wrote an article titled "Direct Determination and Indirect Evaluation of Relative Density and Its Use on Earthwork Construction Projects," published in ASTM STP 523. This ASTM conference had been convened in Los Angeles in June 1972, and this correction was subsequently adopted by

many geotechnical engineers, especially when sampling materials with variable stiffness or in proximity to contacts between soft and stiff materials.

Lacroix and Horn (1973) proposed that nonstandard penetration resistance, N_1, recorded using nonstandard split-spoon or solid cone, could be correlated with standard penetration resistance, N, by considering the differences in driving energy and distance of penetration. They reasoned that the energy required to drive the sampler or cone a given distance, or "depth" (L), was directly proportional to the square of the outside diameter (D) and the distance of penetration and inversely proportional to the energy per blow (weight of hammer multiplied by the height of drop, WH):

$$N = N_1(2\text{ in}/D_1)^2 \times 12\text{ in}/L_1 \times W_1/140\text{ lbs} \times H_1/30\text{ in} = \frac{2N_1W_1H_1}{175D^2L_1} \textit{(2.2)}$$

When this correction is applied to the larger Mod Cal sampler (D_o = 3.0 in. and D_i = 2.4 in.), the predicted correction is reduced to 0.44 N_1, where N, is the nonstandard blow count recorded during driving of the larger Mod Cal sampler. The predicted correction for the smaller Mod Cal sampler would be 0.64 N_1. The depth of penetration (L_I) in the denominator is the distance the sampler was advanced during the sampling round (typically, 18 in. [45.7 cm]). In most instances, this is given as the last 12 in. (30.5 cm) of an 18-in. (45.7-cm) sampling round [so, L_1 = 12 in. (30.5 cm)].

The Lacroix and Horn correction gives a more conservative estimate of the corrected SPT blow counts than by Burmister's (1948) energy correlation (Figure 2.4). The Lacroix and Horn correction appears most valid when sampling is undertaken within 5-10 sample barrel diameters [15-30 in. (38-76 cm)] of contacts with stiffer horizons (such silty or clayey materials above cemented sands or gravels). The stiffness of the base layer causes the blow counts to become elevated because the tip of the sampler senses the stiffer mass beneath its cutting tip.

2.2.5 Side-by-Side Correlations

Between 1991 and 1996, the Rogers (2006) supervised 57 side-by-side sampling rounds using the SPT and 3.0 in Mod Cal samplers in residual soils, colluvium, and Tertiary-age sediments in northern and southern California to estimate the correction factor that seemed most appropriate under general conditions of use. These tests were carried out using the same drill rigs and crews, recording SPT and Mod Cal blow counts at depths of 3.5-33.5 ft (1-10

m). A linear regression analysis of the data points shown in Figure 2.4 gives a correction factor of 0.553. This would be applied to raw Mod Cal blow counts (N_1) for the larger Mod Cal sampler [D_o = 3.0 in. (7.62 cm)]. Note how the regression analyzed figure falls between the Burmister and the Lacroix and Horn predictions, also shown on Figure 2.4. The data become increasingly dispersed with depth and increasing blow counts, likely because of increasing density, confinement, penetration into weathered bedrock materials (which are highly variable) and length of drill rods. No attempt was made to differentiate between cohesive and non-cohesive materials. In addition, none of these data were collected in relatively clean sands, for which much emphasis has been placed in SPT correlations over the past two decades because of their recognized susceptibility to liquefaction and strength loss.

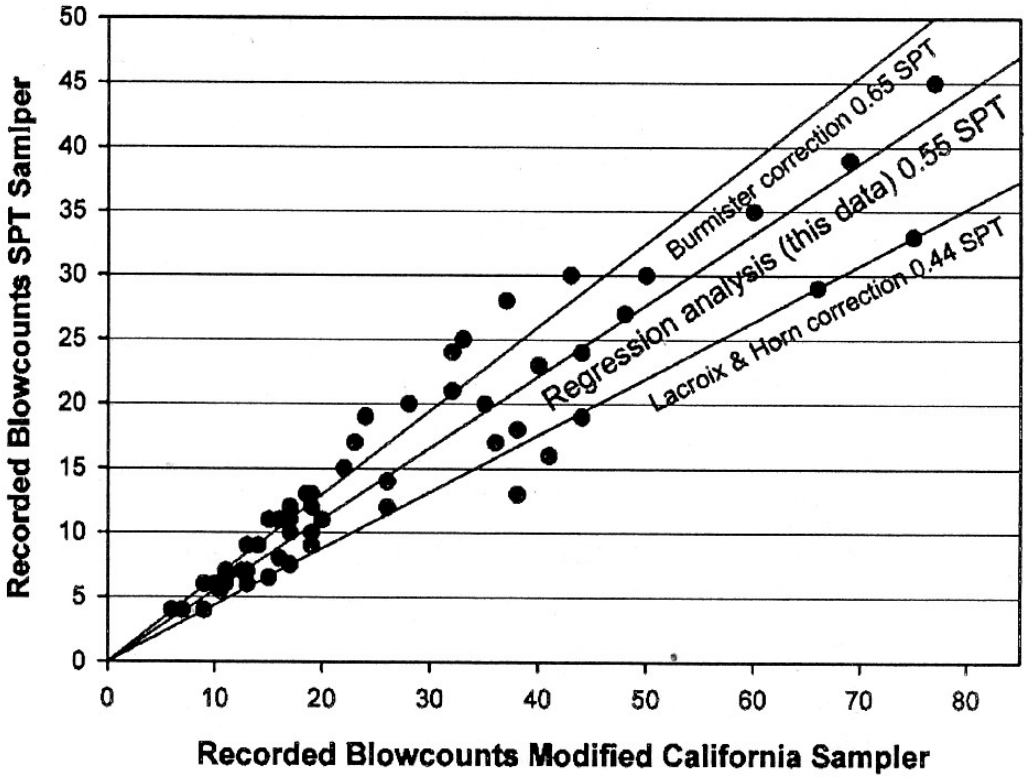


Figure 2.4: Comparison of uncorrected blow counts (N) for 57 drive samples using the Standard Penetration Test (SPT) and larger-diameter Modified California samplers at the same depths and locations. A regression analysis of these data suggests a correction of 0.55, while the methods proposed by Burmister (1948) and LaCroix and Horn (1973) are plotted for comparison (after Rogers, 2006)

2.2.6 Standardized SPT Corrections

The SPT data can be corrected fora number of site-specific factors to improve its repeatability. Burmister's energy correction assumed that the hammer percussion system was

100 percent efficient (a 140-lb hammer dropping 30 in. = 4,200 ft-lbs raw input energy). In Skempton (1986), the procedures for determining a standardized blow count were presented, allowing hammers of varying efficiency to be accounted for. This corrected blow count is referred to as "N_{60}" because the original SPT hammer had about 60 percent efficiency, being comprised of a donut hammer, a smooth cathead, and worn hawser rope, and this is the "standard" to which other blow-count values are compared. Trip release hammers and safety hammers typically exhibit greater energy ratios (ER) than 60 percent (Skempton, 1986). N_{60} is given as

$$N_{60} = \frac{E_m C_B C_S C_R N}{0.60} \qquad (2.3)$$

Where N_{60} is the SPT N-value corrected for field procedures and apparatus, E_m is the hammer efficiency, C_B is the bore hole diameter correction, C_S is the sample barrel correction, C_R is the rod length correction, and N is the raw SPT N-value recorded in the field. Skempton (1986) created a chart for estimating the appropriate values of C_B, C_S, and C_R. Clayton (1990) provided an expanded list of SPT hammer efficiencies (E_m).

D'Appolonia et al. (1969) presented conclusive evidence that confinement increased with depth in sands, and this, along with stress history, affected SPT penetration noticeably (Horn, 2000). Gibbs and Holtz (1957) had presented a method for correcting SPT blow counts for a "standard effective overburden" pressure, N′, so that blow counts in similar materials at different depths could be compared. They defined $N' = C_N N$, where N is the unfactored SPT blow-count value taken in the ground and C_N is a correction factor. The standard effective overburden pressure was given as an effective stress, [σ′ (overburden confinement)]. The correction factor C_N is taken as the reciprocal of the square root of σ′.

The Gibbs and Holtz overburden correction was found lacking when applied to situations where samples were taken from near the bottom of uniform soil deposits, which exhibit higher blow counts because the sampler senses the stiffer material lying below (Figure 6). Liao and Whitman (1986) presented the overburden correction to Skempton's energy-corrected value (N_{60}), known as $(N_1)_{60}$, to account for increasing confinement with depth. The corrected $(N_1)_{60}$ blow count was given as

$$(N_1)_{60} = N_{60} \frac{\sqrt{2000}\ psf}{\sigma_z'} \qquad (2.4)$$

Where σ_z' is vertical effective stress from where the sample recovered.

Robertson and Wride (1997) have modified Skempton's chart and added additional correction factors to those proposed by Liao and Whitman (1986). This chart is reproduced in Table 3. The overburden stress corrected blow count, $(N_1)_{60}$, provides a consistent reference value for penetration resistance. This has become the industry standard in assessments of liquefaction susceptibility (Youd and Idriss, 1997). Robertson and Wride (1997) defined $(N_1)_{60}$ as

$$(N_1)_{60} = NC_N C_E C_B C_R C_S \qquad (2.5)$$

Where N is the raw SPT blow-count value, $C_N = (P_a/\sigma'_{vo})^{0.5}$ (with the restriction that $C_N < 2$) is the correction for effective overburden stress (Liao and Whitman, 1986), P_a is a reference pressure of 100 kPa, σ'_{vo} is the vertical effective stress, $C_E = \frac{ER}{60}\%$ is the correction to account for rod energy, ER is the actual energy ratio of the drill rig used in percent, C_B is a correction for borehole diameter, C_R is a correction for length of the drill rod, and C_S is a correction for the sampling method.

Table 2.3: Recommended corrections for Standard Penetration Test (SPT) blow-count values, taken from Robertson and Wride (1997), as modified from Skempton (1986).

Factors	Equipment Variables	Term	Correction
Overburden pressure		C_N	$(P_a/\sigma'_{vo})^{0.5} \leq 2.0$
Energy ratio	Donut hammer	C_E	0.5 - 1.0
	Safety hammer		0.7 – 1.2
	Automatic hammer		0.8 – 1.5
Borehole diameter (mm)	65 - 115	C_B	1.00
	150		1.05
	200		1.15
Rod length (m)	3 - 4	C_R	0.75
	4 - 6		0.85
	6 - 10		0.95
	10 - 30		1.0
	Over 30		< 1.0
Sampling method	Standard sampler	C_S	1.0
	Sampler without liner		1.1 – 1.3

Since 1986, published correlations have increasingly used corrected $(N_1)_{60}$values with other parameters, such as relative density and angle of internal friction. The$(N_1)_{60}$values are useful in assessments of liquefaction potential, although the most important factor appears to be how

the borehole is stabilized. Mud rotary borings have been found to be vastly superior to hollow stem auger borings in loose saturated sands (Holtz, 2005).

2.3 Procedures Affecting the "N" Values

The number of blows required to drive a split spoon sampler a distance of 12 inches after an initial penetration of 6 inches is referred to as an "N" value or SPT "N" value or N_{SPT} value. There are many factors that can affect the N value. These factors include the hammer type, drill length and type of anvil, blow rate etc. In addition, the N values are influenced by operational procedures as illustrated in Table 2.4, produced from NAVFAC DM 7.1, 1982.

2.4 Factor Affecting the "N" Values

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 an SPT test can vary from about 30% to 80% of the theoretical maximum.

In order to reduce the significant variability of the SPT N value due to the large variation in energy delivered, it has been recommended that the N value be standardized to a specific energy level. This standardization can only be achieved by determining the energy transfer efficiency of the SPT system. Energy transfer efficiency is defined as the transferred energy to the drill rod divided by 350 ft. lbs (nominal energy of SPT hammer).

Table 2.4 Procedures that may affect measured "N" values (after NAVFAC, 1982)

Inadequate cleaning of the borehole	SPT is only partially made in original soil. Sludge may be trapped in the sampler and compressed as the sampler is driven, increasing the blow count. (may prevent sample recovery.)
Not seating the sample spoon on undisturbed material	Incorrect N-values obtained.
Driving of the sample spoon above the bottom of the casing	N-values are increased in sands and reduced in cohesive soils.
Failure to maintain sufficient hydrostatic head in boring	The water table in the borehole must be at least equal to the piezometric level in the sand, otherwise the sand at the bottom of the borehole may be transformed into a loose state.

Attitude of operators	Blow counts for the same soil using the same rig can vary, depending on who is operating the rig, and perhaps the mood of the operator and time of drilling.
Overdrive sampler	Higher blow counts usually result from overdriven sampler
Sampler plugged by gravel	Higher blow counts result when gravel plugs sampler, resistance of loose sand could be highly overestimated.
Plugged casing	High N-values may be recorded for loose sand when sampling below groundwater table. Hydrostatic pressure causes sand to rise and plug casing.
Over washing ahead of casing	Low blow count may result for dense sand since sand is loosened by over washing
Drilling method	Drilling technique (e.g., cased holes vs. mud stabilized holes) may result in different N-values for the same soil.
Free fall of the drive weight is not attained	Using more than 1.5 turns of rope around the drum and/or using wire cable will restrict the fall of the drive weight.
Not using correct weight	Driller frequently supplies drive hammers with weights varying from the standard by as much as 10 lbs.
Weight does not strike the drive cap concentrically	Impact energy is reduced, increasing N-values.
Not using a guide rod	Incorrect N-value obtained.
Not using a good tip on the sampling spoon	If the tip is damaged and reduces the opening or increases the end area the N-value can be increased.
Use of drill rods heavier than standard	With heavier rods more energy is absorbed by the rods causing an increase in the blow count.
Not recording blow counts and penetration accurately	Incorrect N-values obtained.
Incorrect drilling procedures	The SPT was originally developed from wash boring techniques. Drilling procedures that

	seriously disturb the soil will affect the N-value, e.g. drilling with cable tool equipment.
Using drill holes that are too large	Holes greater than 4 in. in diameter are not recommended. Use of larger diameters may result in decreases in the blow count.
Inadequate supervision	Frequently a sampler will be impeded by gravel or cobbles causing a sudden increase in blow count; this is not recognized by an inexperienced observer. (Accurate recording of drilling, sampling, and depth is always required.)
Improper logging of soils	Not describing the sample correctly.
Using too large a pump	Too high a pump capacity will loosen the soil at the base of the hole causing a decrease in blow count.

2.5 Description of Standard Penetration Test (SPT)

An SPT is carried out by driving a standard cylindrical sampler into the soil at the bottom of a borehole. Following removal of the drilling equipment from the borehole at the desired test depth, the sampler is lowered to the bottom of the hole, typically using A or N series drill rods. The sampler is then driven into the soil by striking an anvil attached to the top of the drill rods with a 63.5 kg (140 lb) hammer falling 0.76 m (30 in). The theoretical potential energy of the SPT hammer is therefore 473 joules (350 ft-lbs). The sampler is driven 450 mm (18") and the number of blows required for each 150 mm (6") of penetration is recorded. The total blow number over the interval 150 to 450 mm (6 to 18") is the blow count (N) in blows per foot (bpf). Key details of the SPT sampler and hammer are described in ASTM Standard D1586-84 (1992).

Split Spoon Sampler

Figure 2.2 illustrates the range of acceptable dimensions for split spoon samplers given in ASTM D1586. The standard is much less specific about the required design of the SPT hammer, stating only that the hammer must have a mass of 140 lbs (63.5 kg) and must drop vertically as freely as possible through 30" (0.76 m) before hitting the anvil. As a result, different hammer designs have evolved and they vary considerably. The most commonly used hammer types in North America are the donut, safety, and automatic hammers.

Interest in the assessment of liquefaction potential led to the preparation of ASTM D6066 in 1996. This standard expands the requirements of ASTM D1586 and outlines procedures designed to give reliable and repeatable values of normalized SPT penetration resistances in sands. Specific recommendations are provided as to the equipment to be used. D6066 contains frequent reference to ASTM D4633 although the latter has been allowed to lapse.

Hammer

There are basically three types of hammer used for SPT; donut hammer, safety hammer and automatic hammer as shown in Figure 2.5. The donut hammer was one of the earliest SPT hammers and consists of a donut shaped simple cylindrical 63.5 kg mass falling down a guide rod. The hammer mass is attached to a rope which runs through a pulley situated above the drill rig mast. The hammer is lifted by manually pulling on the free end of the rope wrapped around a rotating cathead, i.e. by applying tension on the rope. The operator drops the hammer, by releasing the tension on the rope, after visually checking that the 30 inch drop height has been attained. Sometimes a winch with a clutch release is used to lift and release the hammer, instead of the rope and cathead system.

The safety hammer was developed to protect rig operators from injury by internalizing the point of impact between the falling mass and the anvil rod (Figure 2.2). The hammer is typically a long steel tube closed at the top. The same lift and release methods used for the donut hammer are also used with the safety hammer. The rope and cathead is the most common method of hammer release used in North America over the last 20-30 years.

Automatic hammers are increasing in popularity. They automate the process of lifting and dropping the hammer mass. Typically, a cam on a chain system grabs the hammer mass at the bottom of its stroke and lifts it until the release point. A hydraulic motor drives the chain cam system. A common type of automatic hammer in the U.S. is the CME automatic hammer manufactured by Central Mine Equipment Company (CME). In British Columbia, several variants of automatic hammer are available, including the Foundex and SDS automatic hammers. These are very similar in design and operation to the CME automatic hammer but differ in the details such as the shape of the hammer mass and the anvil arrangement. One key feature of the automatic hammer is that the drop height varies with the operating speed and at higher speeds the chain drive tends to ‘throw’ the hammer. This can result in actual drop heights exceeding the standard 30 inches, depending on operating speed.

2.6 SPT Hammer System

An SPT hammer system is comprised of the hammer itself, the mechanism that lifts and drops the hammer, (the anvil, stem and anvil or drive-head) and the operator. Two shapes of hammers are in common use; the safety hammer and the donut hammer. The safety hammer, which is relatively long and therefore, has a corresponding small diameter. The safety hammer, has an internal striking ram that greatly reduces the risk of injuries. The donut hammer is short in length and therefore larger in diameter than the safety hammer. The longer safety hammers are more efficient in transferring energy into the rods than the more squat donut hammers. In an energy calibration study by Kovacs et al. (1983), the mean energy ratio delivered by a safety hammer was found to be about 60%, whereas the mean energy ratio for a donut hammer was about 45%.

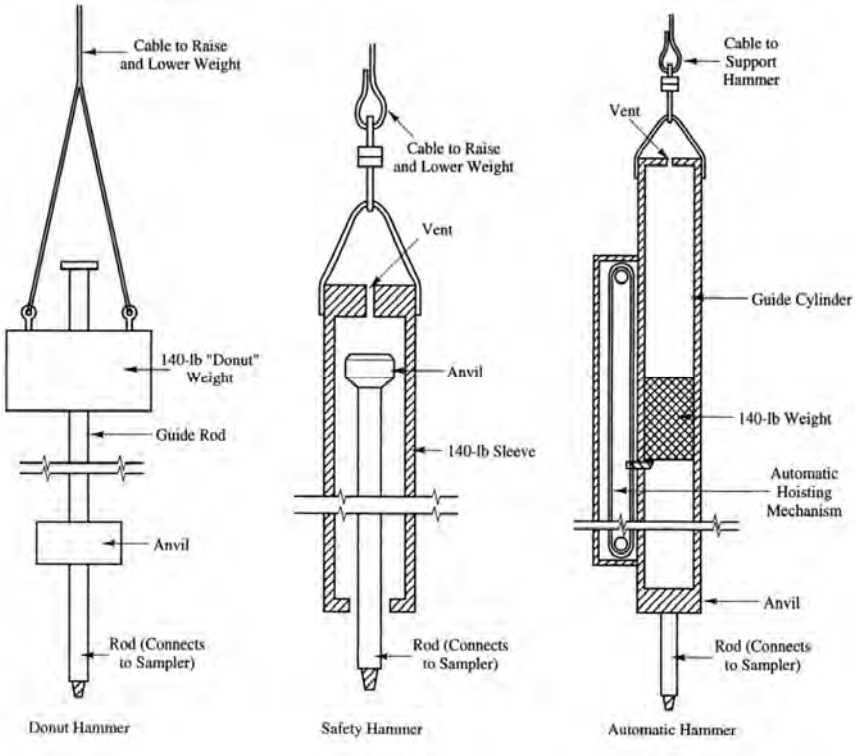


Figure 2.5: Various types of SPT hammers

2.7 SPT Energy and Hammer Type

Several investigators have measured the hammer energy in various SPT systems and found considerable variability. Schmertmann and Palacios (1979) showed experimentally that the measured blow count was inversely proportional to the energy delivered to the drill rods for blow counts less than 50. Because of the variable energy input from different SPT

hammer/rod systems, Seed et al. (1985) suggested that measured blow counts (N-value) be corrected to a reference value of ERi =60% of the potential energy of the SPT hammer at the top of its stroke (60% of 473.4 J = 284 J or 210 ft-lbs). They noted that the safety hammer with rope and cathead release was themost popular method of conducting the SPT at that time, and it had been observed that such a system delivered an average of 60% of the theoretical potential energy. In their view, standardizing at 60% energy would minimize the number of corrections required.

Typical transferred energies or ENTHRU values have been proposed for most hammer types as shown in Table 2.5, extracted from Skempton (1986). It is clear that the method of release has a large effect on the efficiency of the hammer. This generalized approach to dealing with energy variations is questionable because it does not consider differences in the details of the hammer and rod system, which are known to significantly affect transferred energy.

Table 2.5: Summary of Rod Energy Ratios (after Skempton, 1986)

Country	Hammer	Release	Energy ratio, ERi%	$ERi/60$
Japan	Donut	Tombi	78	1.3
	Donut	2 turns of rope	65	1.1
China	Pilcon type	Trip	60	1.0
	Donut	Manual	55	0.9
USA	Safety	2 turns of rope	55	0.9
	Donut	2 turns of rope	45	0.75
UK	Pilcon, Dando	Trip	60	1.0
	Old standard	2 turns of rope	50	0.8

Davidson et al. (1999) documented the range of energies measured by various investigators using a safety hammer operated with a rope and cathead release or an automatic trip release (Table 2.6). Many safety hammers with rope and cathead deliver energies very different from the stated average of 60%. Automatic trip releases lead to more efficient energy transfer.

2.8 Recent Energy Measurements

Numbers of research have been found that are done in the USA to estimate the efficiency of the systems that are commonly being used in different states. Davidson et al. (1999), in a

summary of energy efficiencies as predicted by a number of researchers, indicated that the energy transfer ratio for safety hammers with cathead and rope hoisting mechanism can vary considerably. The range of reported values is from 30% to 96%. For automatic trip hammers, the range is smaller, with a low of 60% and a high of 90%.

Table 2.6: Summary of Average Energy Transfer Ratios (after Davidson et al. 1999)

Study	SPT System- Hammer, Hoist and Release	Energy Ratios (a)
Schmertmann, Smith, Ho (1978)	Safety, rope & cathead	45-70
Goble, Ruchti (1981)	Safety, rope & cathead	76-96
Kovacs, Salomone, Yokel (1981)	Safety, rope & cathead	34-83
Riggs, Mathes, Rassieur (1984)	Safety, rope & cathead Automatic trip	80 (3operators) 88
Seed et al. (1985)	Safety, rope & cathead Automatic trip	63-72 76-90
Riggs (1986)	Safety, rope & cathead	65-90
Skempton (1986)	Safety, rope & cathead	55
Clayton (1990)	Safety, rope & cathead Automatic trip	55-60 60-73
Lamb (1997)	Safety, rope & cathead Automatic trip	67 80
Batchelor, Goble, Berger, Miner (1995)	Safety, rope & cathead Automatic trip	51 69-81

In Bangladesh, majority of the SPT is done manually. A hammer is attached with rope. The workers pull the rope and lift the hammer by 30 inch and release it. The hammer hits the drilling rod and penetrated. Human error is involved in this system. Moreover, number of turns in the pulley varies from site to site. Thus SPT remains in a very non standard crude form in Bangladesh. No previous knowledge or research is known to estimate the efficiency of these systems that are being used in Bangladesh.

2.8.1 Standard Energy N_{60}

There are several publications recommending that a *standard energy ratio* should be adopted for SPT investigations in order to allow reproducible and consistent blow counts among different drill rigs at the same site, regardless of the details used in performing the test. Furthermore, since historically the SPT correlations have been developed using data obtained in the United States and in other countries, the use of an energy ratio will render data

obtained in different countries compatible. First, the theoretical free fall energy of an SPT hammer is determined. This energy is

$$E_{th} = \frac{1}{2}mv^2 = \frac{1}{2}\frac{w}{g}v^2 \qquad (2.5)$$

Where, $E_{th}$is the driving energy (theoretical free fall energy)

m is the hammer mass

w is the weight of the hammer

and *v* is the velocity

Since $v = 2gh$, where *h* is the height of fall then

$$E_{th} = \frac{1}{2}\frac{w}{g}2gh = wh \qquad (2.6)$$

Thus, a 140 lb ram raised 30 inches (2.5 ft) above an impact surface will have a potential energy of$E_{th} = 140 \times 2.5 = 350\ lb - ft.$

The ratio between the actual energy delivered to the sample, (measured energy delivered to the drill rods) to the theoretical free fall energy, yields the energy transfer efficiency or the rod energy ratio in the field:

$$ER_f = \frac{actual\ driving\ energy}{free\ fall\ energy} \qquad (2.7)$$

Where, ER_f is the energy transfer efficiency or rod energy ratio. It was found that the ER_franged from 30% to 90%. With such a wide range in energy ratio it has been suggested by many authors that the SPT be standardized to some energy ratio referred to as the standard energy ratio. The standard energy can be similarly defined as:

$$ER_{st} = \frac{actual\ driving\ energy}{free\ fall\ energy} \qquad (2.7)$$

By noting that the larger the energy ratio, the lower the blow count, and assuming that the energy ratio times the blow count should be a constant for any soil then:

$$ER_f N_f = ER_{st} N_{st} \qquad (2.10)$$

Where,$N_f$is the SPT N value obtained in the field and $N_{st}$is the SPT N value for the standard energy. Thus:

$$N_{st} = N_f \frac{ER_f}{ER_{st}} \qquad (2.11)$$

The past 25 years have seen the advent of more and more efficient hammers. As stated previously, efficiency is defined as the percentage of the theoretical free-fall energy resulting from the impact of the 140 pounds dropping 30 inches. The outcome of the use of these efficient hammers has been N values that are as much as 50% lower than would be measured with hammers made with older designs. This difference in efficiency is one explanation why many have found different N values resulting from two different drill rig hammer systems at the same site. This difference in N values is a concern since empirical correlations between N and geotechnical design parameters were developed from N values that corresponded to less efficient hammers. The question then arises as to what would have been the efficiency of the drill rig systems used in the empirical studies. In other words, what value can we adopt at this point as an efficiency that is representative of the majority of hammer systems before the advent of the safety and automatic trip hammers.

Kovacs (1983) initially suggested that 55% be adopted as the efficiency at which most drill rig systems operated at the time that empirical correlations were made. Seed (1985) suggested instead that 60% be used since it is associated with the safety hammer, the most commonly used SPT hammer in the United States and Bowles (1996) has recommended 70% be used. These estimates are the basis for the proposed correction factors for hammer types. It is recommended herein to use 60% as the standard energy ratio because it will greatly minimize field data corrections since it is associated with the safety hammer that was and still is the most commonly used SPT hammer in the United States. The adoption of this standard energy requires the SPT N values obtained using any hammer to be corrected. The correction is done in accordance with the equation:

$$N_{60} = N_f\left(ER_f/60\right) \qquad (2.12)$$

Where:

N_{60} = SPT N value corrected to 60% of the theoretical free fall hammer energy
N_f = SPT N value obtained in the field
ER_f =rod energy ratio for hammer used in the investigation (measured)

2.8.2 Correction Factors

As stated above, there are numerous factors other than hammer type that are permitted by ASTM D 1586-99 and that affect the N value. Correction factors have been proposed by various authors to account for factors such as the drill stem length and type, the type of anvil,

the blow rate, the use of liners or bore hole fluid and the type of hammer. The standard blow count N_{60} can be computed from the measured N_f from the following general equation (excluding the overburden corrections):

$$N_{60} = N_f \times n_1 \times n_2 \times n_3 \times n_4 \times n_5 \times n_6 \qquad (2.13)$$

Where,

n_1 =energy correction factor

n_2 =rod length correction factor

n_3 =liner correction factor

n_4 =borehole diameter correction factor

n_5 =anvil correction factor

n_6 =blow count frequency correction factor

By far the most important correction to be made to N_f is for the energy delivered to the drill rods. The energy delivered from the hammer depends on the way the hammer is lifted and released, and on the design of the hammer. The correction factor is defined as n_1. For a standard energy of 60% then

$$Correction\ factor = \frac{average\ transferred\ energy\ ratio}{60} \qquad (2.14a)$$

$$n_1 = \frac{ER_f}{60} \qquad (2.14b)$$

Where, ER_f is the average energy ratio determined in the field.

It has been shown that when the length of the drill rod is less than 10ft, a considerable amount of energy is reflected back in the rod reducing the energy available for driving the sampling tube into the ground, thus it is recommended that the N values should be corrected for short lengths of rods. The correction factor for length is n_2.

The ASTM sampler that is used in the United States has a $1\frac{3}{8}$in. I.D shoe and a barrel that can be fitted with liners to provide a constant I.D of $1\frac{3}{8}$ in. However the barrel is often used without liners. In this case the I.D. is $1\frac{1}{2}$ in. and there is less friction developed inside the sampling tube, which in turn reduces the measured N values. It has been shown that the use of the ASTM sampler without the liner leads to 10% to 30% lower N values. It was also shown that the effect is smaller for looser sands and larger for denser sands. It is thus recommended that the measured N values should be corrected for the use of the liner. The

correction factor is n_3.SPT N values are corrected if they are made in boreholes larger than 4.5 inches. When boreholes are larger than 4.5 inches, measured N values are lower than they would be for a smaller diameter hole. The correction factor is n_4.When the hammer falls during the SPT testing, it stricks an anvil attached to the drill rod stem. The anvil can vary in shape, size and weight. The amount of energy transferred to the drill rods depends on the weight of the anvil. The correction factor is n_5.Another correction $n_6$is for blow count frequency that applies for sands below the water table.

2.9 Concluding Remarks

Literature review reveals that Standard Penetration Test has evolved over a period of 100 years, but still can elicit incorrect data under particular subsurface conditions that are often overlooked. The energy transfer mechanism or efficiency of hammer during SPT still remains as a matter of controversy. In the context of Bangladesh, the available literature on this aspect of SPT are very few. As such, it is felt necessary that a study should be carried out on the hammer efficiency of SPT in the context of Bangladesh.

Chapter 3
ENERGY MEASURING SYSTEM

3.1 General

To measure the energy transmitted from the hammer to the drill string, some form of instrumented equipment is required. The equipment should have strain gauges for obtaining force measurements and accelerometers for obtaining velocity data. The equipment should be capable of recording and displaying the velocity and force waveforms as well as calculating energy values using both the F^2 and FV methods.

3.1.1 SPT Analyzer

The SPT analyzer used in this research is manufactured by Pile Dynamics, Inc. (PDA) The analyzer consisted of an instrumented 2-foot long NW drill rod section, a hand-held unit to read and store data and the necessary wiring to connect the gauges on the instrumented rod to the hand-held unit and the software for use in evaluating the data.

3.1.2 Rod and Sensors

Foil strain gauges (350 ohm) glued directly onto the rod measure strain, which is converted to force using the cross-sectional area and modulus of elasticity of the rod. Two piezo-resistant accelerometers are housed in a rigid aluminum block that is mounted to the rod. The acceleration measured by the accelerometer is integrated to obtain velocity. The instrumented rod is affixed to the top of the drill string just below the anvil during testing.

3.1.3 Hand-Held Unit

The unit has an LCD touch-screen for entering rod area and length, descriptions and names, and user comments. The programmed screens allow for data control and review. When the test is in progress, the beginning of the hammer blow triggers the analyzer to begin recording data. The analog data from the gauges are digitized at 20 kHz for a period of 100 milliseconds. These data are continuously displayed on the screen as the force wave (from the strain gauges) and the velocity wave (from the integral of the data from the accelerometers). The trace of the velocity wave is scaled such that it is proportional to the force wave; it is

scaled at the force scale divided by the impedance, Z. Four channels of data are recorded for each blow: 2 forces and 2 velocities. The data are saved for a user-selected blow frequency in the memory of the unit. Raw data and energy-related quantities are sorted in the memory until downloaded into a computer using PDI software. After analyzing the data, the data were plotted using Excel.

3.2 Energy Measurement Methods

Two methods can be used to calculate maximum transferred energy to the drill rods. The first method uses the integration of the product of the force and velocity record over time (Force Velocity Method) and is referred to as EFV. For this method the transferred energy is determined by:

$$EFV = \int F(t)\,V(t)dt \qquad (3.1)$$

Where:

F =the force at time t

V =the velocity at time t

The integration begins at impact (time the energy transfer begins) and ends at the time at which energy transferred to the rod reaches a maximum value (i.e., integration over the entire force and velocity record). This method is theoretically sound and requires no correction factors (Aboumatar and Goble 1997).

The second method calculates transferred energy to the drill rod using the square of the force record (F_2 Method) referred to as $EF2$ and is as follows:

$$EF2 = (c/EA)\int [F(t)]^2\,dt \qquad (3.2)$$

Where:

c =stress wave propagation speed in the drill rod

E =modulus of elasticity of the drill rod

A =cross sectional area of the drill rod

F =the force at time t

The integration begins at the time of impact and ends at the time of the first occurrence of a zero force after impact. The force squared method is described in ASTM D4633-86 and requires the use of three correction constants. These constants correct for the distance

between the anvil and the measurement device, the rod length and the ratio of the actual to the theoretical time at which the force at the rod top becomes equal to zero. There is uncertainty associated with the use of these correction constants. Furthermore, the third correction is only valid for actual times of occurrence of zero force greater than 90% and less than 120% of the theoretical time calculated by $2L/c$, where L equals the rod length and c is the wave speed in the steel rods. If this is not the case, the $EF2$ method can not be used to evaluate energy. In reality, due to changes in impedance with different rod cross-section changes, presence of collars and adaptors in the drill string connector conditions, etc; reflections will occur before the first compression wave reaches the end of the sampler. The result of this is that the time of zero force may fall outside the limit and thus the method is frequently invalid for SPT testing. The first method, the force velocity method is unaffected by changes in cross-sectional area and is based on measured values. This method is believed to be exact and is the method used in this project.

3.3 Previous Work of Energy Measurement Methods

3.3.1 Kinetic Energy at Hammer Impact

The kinetic energy of the hammer reaches a maximum the instant before the hammer strikes the anvil rod. The kinetic energy on impact represents the energy available to drive the rods and sampler into the soil at the base of the borehole. The kinetic energy (K.E.) at impact of the hammer is:

$$KE = \frac{1}{2}mv_i^2 \qquad (3.3)$$

where m is the hammer mass and V_i is the peak velocity just before impact. For a mass in free fall, the impact velocity can be calculated by equating the potential energy change to the kinetic energy at impact as given by the expression:

$$v_i = \sqrt{2gh} \qquad (3.4)$$

i.e., the impact velocity varies with the square root of the drop height. For a 63.5 kg (140 lb) hammer falling 76 cm (30 inches), the free fall velocity will be 3.87 m/s (12.7 ft/s). For a perfectly efficient impact, this velocity would result in an ENTHRU of 100% of the theoretical potential energy. Kovacs and Salomone (1982) used photovoltaic reflective scanners to record hammer drop height and peak velocity for a large number of donut

and safety hammer blows. They recorded energy losses of 21% to 25% of the total potential energy for donut hammers and 26% to 31% for safety hammers.

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 incorporated hollow-centre, strain gauge load cells near the top and bottom of the drill rods to measure the force-time histories of the stress waves. The force data were used to calculate energy transfer in the rods and the energy loss in the sampling process.

Schmertmann and his co-workers found that the energy in the rods or ENTHRU was less than the hammer impact energy. They attributed the difference to the energy lost to heat during hammer impact as well as energy trapped in the anvil. They found that it was this ENTHRU, not the energy in the hammer at impact, which produced the sampler penetration that determined the SPT N-value. They showed field data to confirm that the N-value varies inversely with the energy delivered into the drill rods.

The energy calculation was based on the theory of 1-D wave propagation in a rod. In an elastic medium, the energy transfer may be considered in its simplest form to consist of a single elastic stress wave front generated by the impact of the hammer traveling down the rods until it reaches an interface as illustrated in Figure 3.2 The passage of a stress wave past a point consists of a change in stress and a change in particle motion.

The change of particle motion with time, dx/dt, is the particle velocity, $V(t)$. The particle velocity should be distinguished from the propagation velocity of the stress wave front, c. The magnitude and frequency of the particle oscillation reflect the amplitude and frequency of the wave. The propagation velocity, c, is a constant governed by the elastic modulus and material density as follows:

$$c = (E/\rho)^{0.5} \qquad (3.5)$$

Where:

E is Young's modulus (for steel E= 207 GPa or 30,000 ksi)

ρ is the material density (steel = 7940 kg/m3 or 492 lbs/ft^3).

In a long uniform rod, the first interface encountered will be the tip of the rod. For a free end, the energy has nowhere to go and is reflected back up the rod. Because of the boundary

conditions, the compression wave returns as a tension wave. As the wave travels up the rod, the resultant stress at any point is the sum of the original compressive stress and the returning tensile stress, i.e. the stress is reduced. The resultant velocity is also the sum of the particle velocity of the downward traveling wave and the particle velocity of the upward traveling return wave.

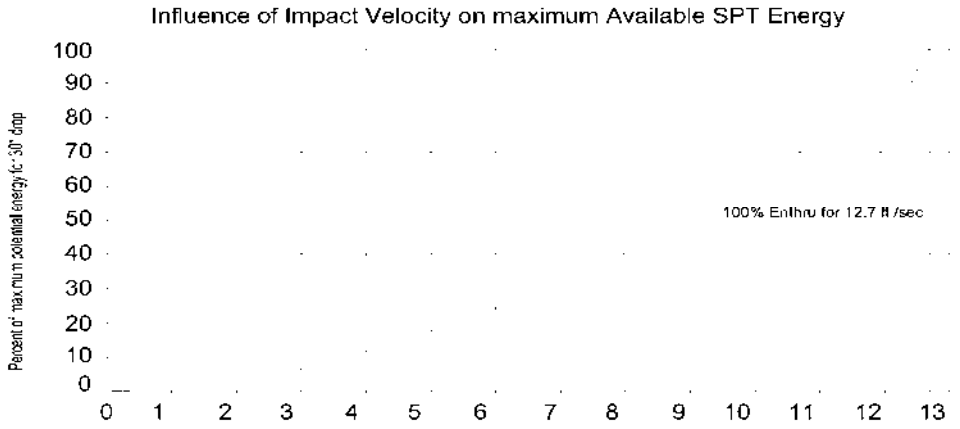


Figure 3.1: Influence of Impact Velocity on Maximum Available SPT Energy

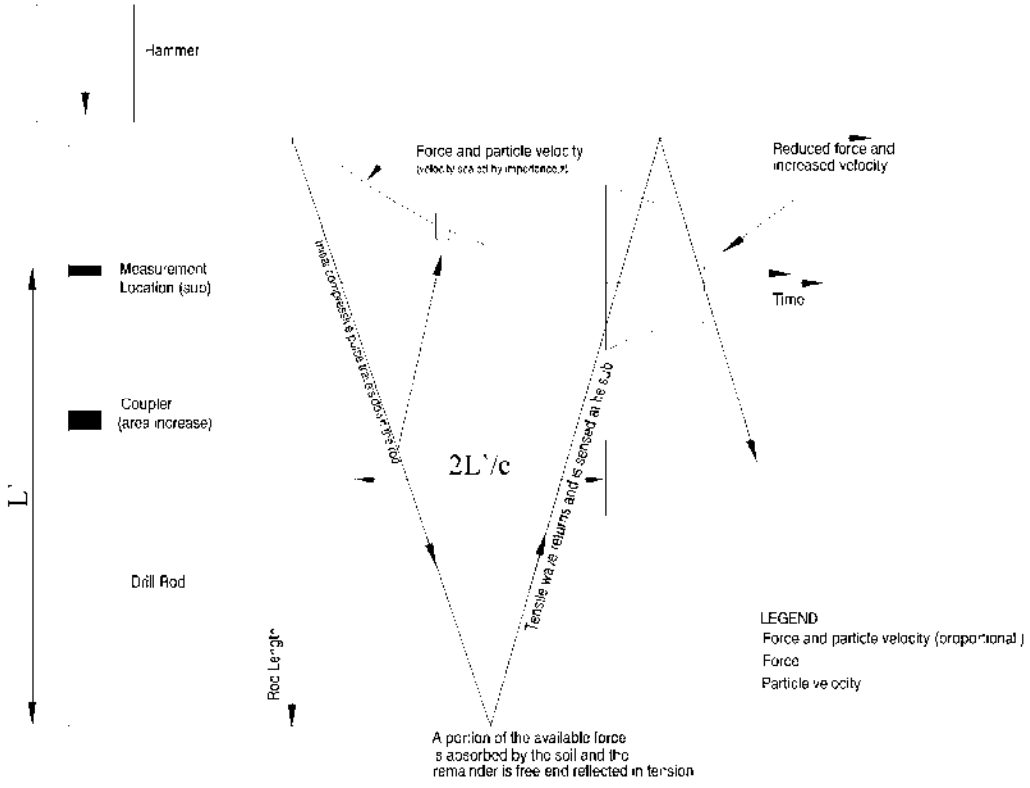


Figure 3.2: Idealized wave transmission and measured response in the SPT.

After impact, the measured force near the top of the drill rods declines from its peak value until the arrival of the tensile reflection from the tip causes it to go sharply negative (tension). This tensile wave return occurs at a time, $t = 2L'/c$ after impact, where L' is the length of rod below the point of measurement. The measured velocity would be expected to increase at this point, as the particles are pulled downward by the returning tension wave.

Schmertmann and Palacios (1979) found that the hammer and rods remain in contact only until tension cut-off (return of major tensile stress wave reflected from bottom of drill rods) occurs. At this point, transfer of energy from hammer to rods ceases. The hammer-rod contact time, $2L/c$, where $L = L' + \Delta L$ and ΔL is the distance between the instrumentation and the hammer rod contact, is longer for longer rods resulting theoretically in more hammer energy entering the rods. For a body undergoing motion, the increment of work done over a time interval centered at a time t_1 is given by

$$dW = F_1 dx \qquad (3.6)$$

Where F_1, is the force in the direction of motion at time t_1 and dx is an increment of displacement. Integration of Equation (3.6) yields the total work done by the force to produce the displacement x:

$$W = \int F_1 \, dx \qquad (3.7)$$

Since the hammer impact force in a rod is variable with time, it is more convenient to express the work done, or energy, as a function of time, i.e.

$$E_n(t) = W = \int F(t) \, V(t) dt \qquad (3.8)$$

Where, $E_n\,(t)$ is the energy, $F(t)$ is the force and $V(t) = dx/dt$ is the particle velocity, all with reference to a point in the rod. Equation (3.8) is the fundamental equation describing energy in a rod as a function of time. Energy can be calculated if the force and velocity time histories are known at a point in the rod. The maximum value calculated from Equation (3.8) is the maximum transferred energy or ENTHRU in the rod. Equation (3.8) represents the *FV* method of calculation of SPT energy transfer.

For impact wave propagation in one direction in a uniform unsupported elastic rod, it can be shown (Timoshenko and Goodier, 1970) that:

$$F(t) = V(t)EA/c \qquad (3.9)$$

In which the quantity EA/c is referred to as the impedance, Z, of the rod, and A is the cross-sectional area of the material through which the wave is travelling. The impedance is a material constant. Consequently, in an elastic rod of uniform cross-section, the particle velocity is proportional to the force at a point, as long as there are no wave reflections from external forces acting on the rod. This proportionality relationship is the basis for evaluating the soil resistance from stress wave measurements in piles.

As long as force and velocity are proportional, Equation (3.10) can be substituted into Equation (3.11), either for force or velocity, to obtain:

$$E_n(t) = EA/c \int V^2(t)dt \qquad (3.10)$$

$$E_n(t) = c/EA \int F^2(t)dt \qquad (3.11)$$

Equations (3.10) and (3.11) show that the energy at a point in the rod can be computed with only one measured quantity, i.e. either from a velocity or force time history. Both equations inherently assume proportionality between force and particle velocity at the measuring point in the rod during the first compression pulse, and require that the time limits of the first compression pulse be predetermined. Equation (3.11) is referred to in this report as the force integration or $F2$ method for calculating energy. This is the method specified in ISSMFE (1988) for SPT energy measurement and was covered by ASTM Standard D4633-86 until it was allowed to lapse in 1998.

The assumption of proportionality between measured force and velocity is only valid at a given point in the rod until the first reflection returns from below the measurement point. In an idealized uniform rod system, the first reflection will be from the tip. In real rod strings, earlier reflections will occur from impedance changes at couplers located along the rod string. Such a case is illustrated in Figure 3.2. The effect of the departure from proportionality will depend on the magnitude of the impedance change causing the reflection. The effect of reflections on measured force, velocity and energy can be calculated for simple cases using the theory of 1-D wave propagation in uniform rods. In summary, the FV method, Equation (3.8), is the fundamental method for calculating energy in a rod due to hammer impact. It avoids the force-velocity proportionality assumption inherent in Equation

(3.11) and requires neither predetermination of the integration time nor input of E, A or c, all of which are needed for the force integration method.

3.4 The State of Practice in Energy Measurement

The basic force-velocity approach to energy measurement is the standard practice in dynamic monitoring of piles during driving (ASTM D4945-89). The method is gradually gaining acceptance for energy measurement in SPT testing and energy monitoring systems based on FV are commercially available. According to Goble (2001), the FV method is now the dominant energy measurement method in the U.S. However, the $F2$ method is still used. ASTM D6066 makes reference to D-4633 even though the latter has been allowed to lapse. In addition, the bulk of the SPT energy database referred to in such widely quoted publications as Skempton (1986), Canadian Foundation Engineering Manual (1992) and NCEER (1997) was gathered using corrections for energy based on the $F2$ approach. The ISSMFE Reference Test Procedure for Energy Measurement is also based on the $F2$ approach. An ASTM committee is currently drafting a new standard on energy measurement that will include the FV approach.

The force integration method of measuring SPT energy consists of attaching a load cell near the top of the drill rods and measuring the force time history during hammer impact. The summation is carried out from the time that the downward propagating stress wave first passes the measurement point until time $t = 2L/c$. High frequency data sampling is used so $F(t)$ is constant over the time step dt. Modern instrumentation typically consists of electrical resistance strain auges bonded to or bolted on to a rod of the type used in the rest of the drill string (called a transducer rod or instrumentation subassembly). The transducer rod is usually placed in the string of drill rods directly below the anvil rod. Piezo-resistive and piezo-electric load cells placed in series in the drill string may also be used to record force data but it is generally considered desirable to limit the number of impedance interfaces around the measurement location. Figure 3.3 shows an idealized force-time waveform recorded by a load cell in the drill rods. The energy is calculated in ASTM D4633 based on Equation (3.11).

3.5 Energy Measurement by Force Velocity Integration

The force velocity integration (FV) method of measuring SPT energy differs from the $F2$ method in that additional instrumentation is required to record the variation of particle

velocity with time during stress wave transfer. This additional instrumentation consists of accelerometers mounted near the top of the drill rods, very close to where force is measured.

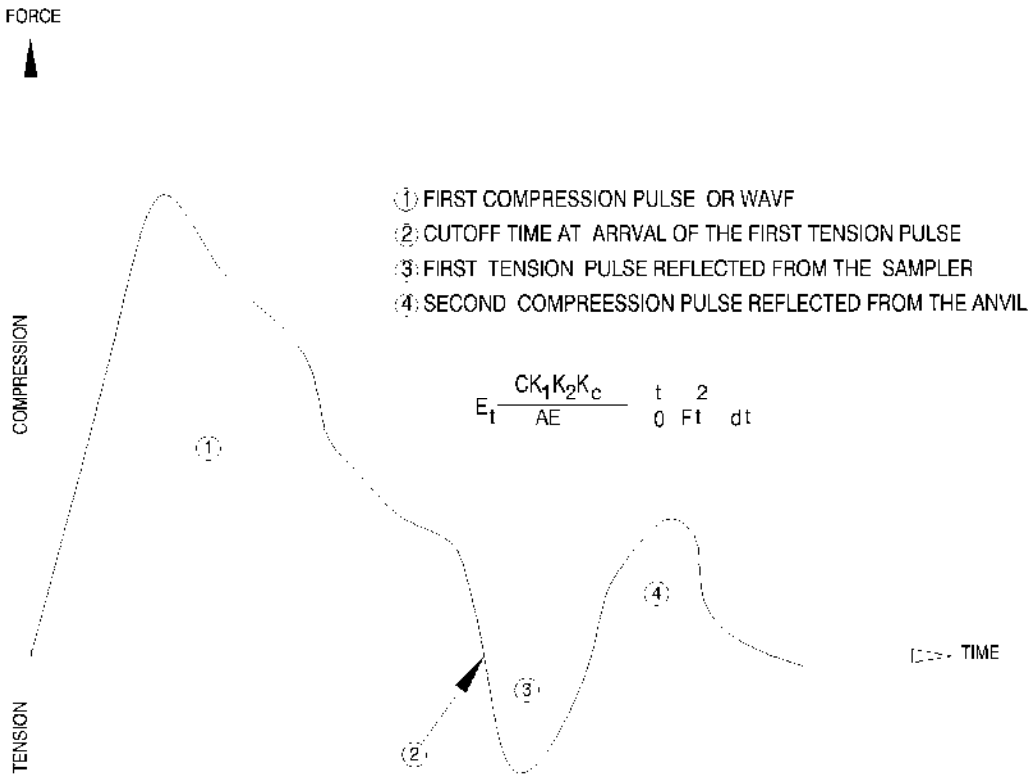


Figure 3.3: ASTM Sample figure for Energy Measurement

Data are recorded during wave transmission with the strain measurements converted to force and the acceleration integrated to obtain velocity. Scaled velocity, i.e. ZV, where Z is the rod impedance and force are displayed on a computer screen during testing. The theory indicates that force and scaled velocity traces should be identical provided no upward-travelling reflections are received at the transducers. Observed departures from force velocity proportionality allow identification of such reflections. As can be seen in Figure (3.4), the $F2$ energy obtained by integration of the force trace will thereafter be in error by some amount that depends on the magnitude of the reflection. The FV energy is unaffected. Theoretically, FV energy can be calculated using Equation (3.8) and integration can be continued to the end of the record or until the force and velocity drop to zero. The FV energy should represent the actual energy transferred to the rods provided force and velocity measurements are accurate. If energy is indeed trapped in the hammer at short rod lengths, then FV energy should increase with depth.

3.6 Comparisons of $F2$ And FV Energy

The FV method was first used for energy monitoring in SPT testing in the early 1990's (Sy and Campanella 1991). Morgano and Liang (1992) found that for the FV approach, the measured energy increased with the length of the rods and reached a maximum at a rod length of about 40 feet to 50 feet. They derived equivalent $K2$ values from their field testing and found that they were much lower than the theoretical values applied in the $F2$ approach. They concluded that this was primarily due to additional energy transfer beyond $2L/c$ accounted for in the force-velocity integration method.

Butler (1997) and Davidson et al. (1999) carried out FV energy measurements on a considerable number of hammer systems on a variety of drill rigs. In both studies, an increase in transferred energy with depth was observed. Davidson et al. (1999) noted a "moderate" relationship between rod length and energy transfer when individual systems were considered. The increase in energy was most apparent for automatic hammer systems and supported the findings of Morgano and Liang (1992).

Measurement of both force and velocity allows recognition of reflections arriving at the transducers before the major return from the sampler tip. It is also possible to compare $F2$ and FV energies ($ERF2\ vs\ ERFV$). Butler (1997) found that $ERFV$ values were higher than $ERF2$ energies for low blow counts (N<10) and lower than $ERF2$ for high blow counts (N>50). Davidson et al. (1999) obtained results that did not show the same trend. They found that $ERFV$ was generally greater than ERF2, particularly for shorter rod lengths.

3.7 Hammer Impact

Figure 3.2 illustrates several stages in the formation and propagation of stress waves within a simple hammer and rod system following hammer impact. A transducer element for recording force and velocity versus time is indicated near the bottom of the anvil rod. The impedance ratio between hammer and anvil is denoted by $r = AA / AH$.

In Figure 3.4, the hammer is falling with uniform velocity (VHi) and the anvil rod is at rest. There are no axial forces in the hammer or anvil rod. When the hammer strikes the anvil rod, the impact surface of the hammer must decelerate and the impact surface of the anvil rod must accelerate so that the velocities of the two surfaces are equal (continuity requirement).

The surface accelerations are accommodated by elastic strain within the two bodies on either side of the plane of impact. The magnitude of the resulting axial forces may be calculated from elastic theory and must satisfy force equilibrium across the plane of impact. In this case, there were no pre-existing forces in the hammer or anvil so the force in the two bodies must be equal. The resulting stress is lower in the hammer than in the rods because the hammer cross-sectional area is larger.

After impact, compression stress waves move away from the plane of impact as shown in Figure 3.4b. The stress wave induced in the hammer moves upward and the stress wave in the anvil rod moves downward, both waves traveling at velocity, c.

3.7.1 Wave Propagation in Hammer

In Figure 3.4c, the upward propagating stress wave arrives at the top of the hammer and reflects as a tension wave with equal but opposite force (tension). The tension wave propagates downward. The new, total particle velocity behind the downward propagating stress wave is equal to the sum of the initial hammer fall velocity (VHi), the upward particle velocity of the original stress wave and the equal upward particle velocity of the reflected wave. The total force is equal to zero behind the reflected wave front (Figure 3.4d) but the velocity will not be zero unless the hammer and anvil have the same impedance.

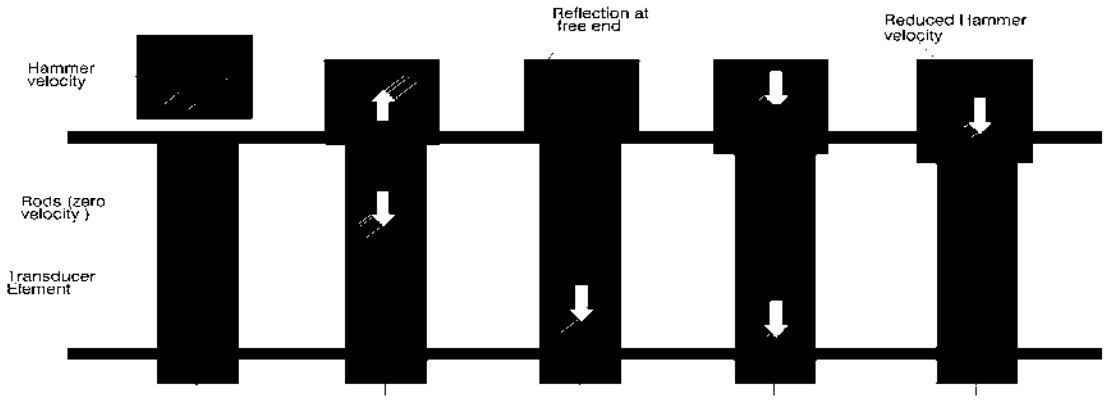


Figure 3.4: Stress Wave Propagation at Hammer/Anvil Contact

At time $t = 2LH/c$, where LH is the length of the hammer, the hammer will be momentarily stress free and moving with a uniform velocity less than the original impact velocity. This situation is depicted in Figure 3.4e. As indicated, the compression wave in the anvil rod has now reached the transducer package, which is measuring FA and VA. Provided the hammer is

still in contact with the anvil rod, a portion of the tensile wave will be reflected back up the hammer and a portion will be transmitted down the rods as a tensile wave. Proportion of transmission and reflection is governed by impedance ratio of the hammer to the anvil rod, r.

3.8 Effect of Reflections on Energy Measurement.

The typical effect on measured force and velocity due to compressive reflections from an interface (in this case a coupler) below the transducer is shown schematically in Figure 3.5. The measured force increases and the velocity reduced. The force and velocity traces are no longer proportional. For a tensile reflection from below the transducer, as typically occurs from the SPT sampler, the measured force would decrease and the velocity would increase. Again proportionality will not exist in the measured wave traces.

As noted in Energy Measurement Method while proportionality of force and velocity exists, the energy at a point in the rod can be computed given only one measured quantity, i.e. based on either the velocity or force time history. As the assumption of proportionality between force and velocity is only valid at a given point in the rod until the first reflection returns from below the measurement point, calculations of energy based on one measured quantity will not give the correct energy after such a reflection arrives at the instrumentation package. For the case illustrated in Figure 3.5, the energy calculated using the force curve will be greater than that calculated from the correct FV method. Conversely, a tensile reflection will cause the $F2$ energy to be less than the FV energy. The FV energy represents the actual energy transmitted through the rods, regardless of the wave reflections due to rod impedances.

3.9 Effect of Hammer Geometry

The simple case of a hammer striking a rod was used in order to verify the model and confirm the work of Schmertmann and Palacios. For this case with a hammer and anvil both made of steel, the impedance ratio (r) is equivalent to the arearatio, an anvil/a hammer. Figure 3.6 shows the calculated variation of peak force for a 140 lb hammer hitting AW rods (cross-sectional area of 1.24 in^2) and NW rods (A rods =1.44 in^2). No anvil has been assumed. The Figure illustrates the following:

(i) For a short fat hammer, the impedance ratio is small and the peak force could be as high as about 27 kips (115 kN) on AW rods.

(ii) For a long thin hammer, the force would be lower. In the extreme, a hammer with the same cross-sectional area as the AW rods ($r = 1.0$) would cause a force of about 14 kips (62 kN).

(iii) For a hammer hitting NW rods (cross-sectional area=1.44 in^2), a given hammer will result in a higher force than in AW rods. A short fat hammer creates a forceof about 32 kips and a long slender one of the same area as the rods would create 16 kips.

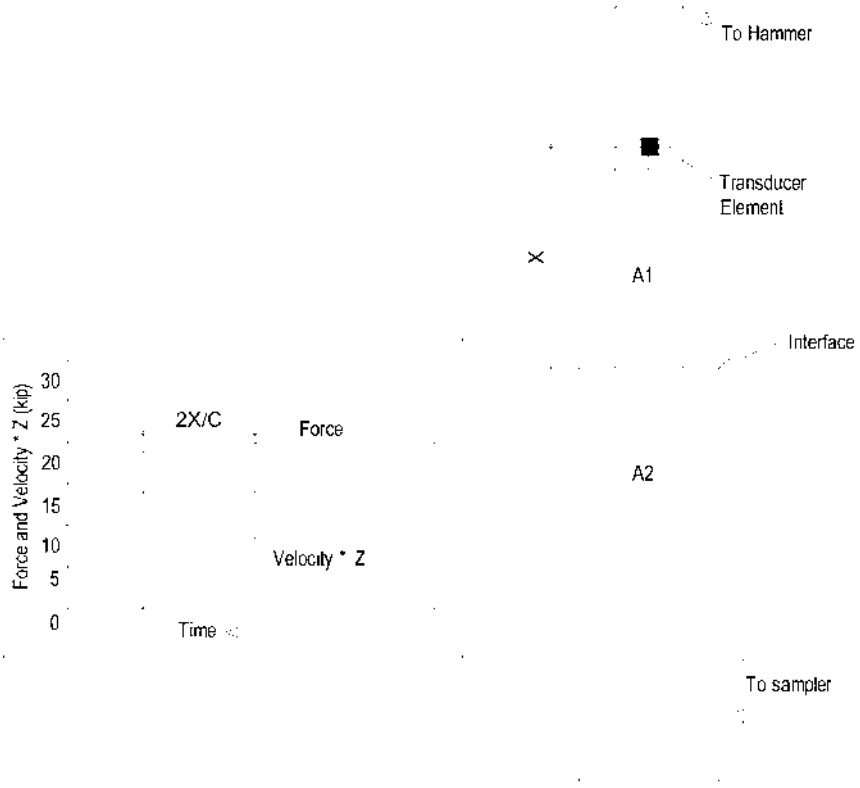


Figure 3.5: Effect of Compressive Reflection

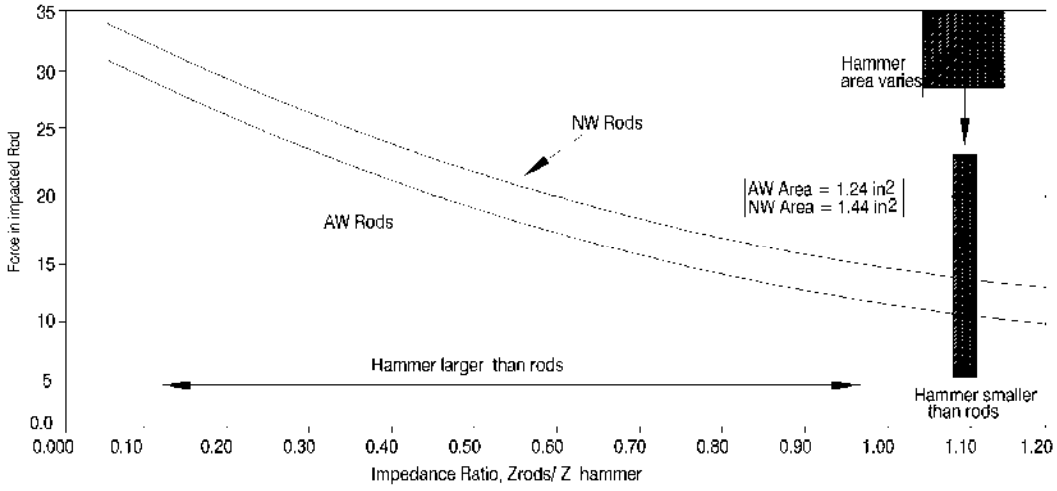


Figure 3.6: Calculation of Force Upon Impact of Steel Hammer on Steel Rods

3.10 Effect of Hammer Length

For a simple set-up involving only a hammer striking a rod string, theory predicts that the effect of lengthening the hammer is to lengthen the initial pulse width and to decrease the magnitude of the initial force, since the cross-sectional area of the longer hammer will be less in order to maintain the same mass. In case of a simple laboratory test arrangement used to carry out tests where only the length of hammer was altered in two successive blows. The measured results are also presented as follows.

In this case, the area of the hammer was not increased to maintain similar hammer mass between tests, i.e., the 3 ft hammer mass was 24.7 lbs (11.2 kg) and the 1 ft hammer was 8.2 lbs (3.7 kg). Based on the details of the testing arrangement, one would expect that the level of force should be similar in the two tests (same hammer areas) and the major initial pulse width should be significantly longer for the longer hammer. Signal rise times and coupler reflections make it difficult to completely isolate the length effect.

3.11 Effect of Loose Joints

The influence of loose joints on the measured force, velocity and energy is an important issue since couplers often become loose during field testing and in many cases the entire rod string is only hand tightened. During the course of this research, it has become apparent that the action of the hammer striking the rods and subsequent transmission of stress waves in the rod string tends to cause the joints to become loose. Even joints tightened with pipe wrenches tend to come loose after a few hammer blows and it was necessary to wrap the threads with tape before connection in order to study the effect of tight vs. loose joints.

It was observed that tapered threads (i.e. NWJ and AWJ) have a greater propensity for loosening than do box threads (AW and NW) and taper threaded joints are significantly more slack when loose. This is to be expected as tapered threads are specifically designed to loosen easily. It is likely that the thin male section of the tapered threads quickly loses physical contact with the female end and provides less lateral support.

3.12 Rod Type

For a given SPT set-up (hammer & anvil system and rod length) there will be differences in the levels of force, particle velocity and rate of energy input depending on

the type of drill rods used. The most common types of rods used in the SPT will be AW, AWJ, NW and NWJ. The NW and NWJ rods are of the same diameter and area while AW and AWJ are typically different in area. Conventional rod dimensions are shown in

Table 3.1 Different rod type and their cross sectional area

Rod Type	Cross-sectional area (in^2)	Comments
AW	1.18	Square thread
AWJ	0.92	Tapered thread
NW	1.44	Square thread
NWJ	1.44	Tapered thread

Christensen Products also sells an "Ultra Light" AWJ rod which has a nominal internal diameter of 1.470 in (cross-sectional area of 0.708 in2 or only 77% of the normal AWJ rod. The Longyear Catalogue shows an AW I.D. of 1.219 inches, which results in a cross-sectional area 5% greater than that shown in the table above. Clearly, there are variations in each rod type in industry. Rods from different manufacturers will have slightly different impedances and if mixed in a rod string will introduce additional reflections. Rod corrosion or wear and tear will also change the rod impedance.

In general, the NW/NWJ will have the largest cross-sectional area followed by the AW and the AWJ, respectively. For a given SPT test, where the only variable is the rod type, the highest forces will be measured in the NW/NWJ followed by the AW and AWJ respectively.

For energy differences due to rod type, the trend is the same for both modeled and measured data. At short rod lengths (10 ft.), the larger area rods tend to allow the input of energy more quickly than rods of smaller area. At longer rod lengths (40ft), the differences in energy due to rod type are small. Simple modeling showed that the AW and AWJ energy curves were at the same level at 40ft depth and only slightly lower than the NW/NWJ rods.

It was noted that the "J" type threads, while preferred by drillers because of ease of use, had some undesirable effects on the quality of energy measurements. The tapered "J" type threads tend to be more massive than the box threads and the reflections resulting from them are larger in magnitude and more recognizable on recorded force and velocity traces. This characteristic makes $F2$ energy measurements less reliable

compared to $F2$ energy measurements on equivalent box type threads. This trend is particularly noticeable for NWJ rods and to a lesser degree for AWJ rods.

Another trait of the "J" type threads was a greater propensity towards loosening during SPT testing compared with the box threads. Even after tightening with a wrench, both types tended to become loose after only a few blows but the tapered threads tended to loosen more easily. Also, after becoming slightly loose, the tapered threads tended to have more slack and greater lateral mobility compared to the box threads. Loose rods were shown to result in delayed wave returns from the sampler beyond $t = 2L/c$ and to reduce the number of $2L/c$ cycles recorded before cessation of stress wave activity.

3.13 Effect of Accelerometer

Particle velocity is computed from the acceleration signal and is the most difficult parameter to derive accurately in SPT energy measurement systems. The important characteristics of an accelerometer for SPT testing are:

(i) low mass,
(ii) good sensitivity,
(iii) ample frequency response,
(iv) low transverse sensitivity,
(v) low thermal sensitivity,
(vi) no phase shift,
(vii) high dynamic range,
(viii) good linearity,
(ix) a high resonant frequency.

It is important that the accelerometer be responsive and accurate at the levels of acceleration and frequency content present in SPT testing.

3.13.1 Calibration

It is difficult to calibrate accelerometers in a shock environment at frequency levels similar to those that the instrument will see in field conditions. Accelerometer manufacturers will give a calibration with a high level of precision (+/- 2% is often

quoted) but will qualify this by clearly stating that the calibration applies to levels of acceleration that are only fractions of the full scale potential of the instrument. NIST traceable calibrations are available for all accelerometers with an uncertainty level of5%. Calibration can be accomplished through techniques such as the ball-drop or Hopkinson bar arrangement but it is hard to duplicate field conditions. In this research, satisfactory performance was achieved using the manufacturer's calibration.

3.14 Conversion to Engineering Units

Computing the desired engineering units from the instrument response usually involves identifying the change in transducer voltage from the background value that is being caused by the effect being measured and multiplying by the appropriate calibration factor.

The method of determining the baseline can have an effect on the results. The PDI SPT Analyzer system employs "signal rotation" which is based on the concept that the velocity must return to zero once all stress-waves have dissipated. To use this approach, the record length must be sufficient to ensure that the velocity returns to zero at the end of the trace. Other approaches are to consider the average of the readings taken in a short monitoring period before the impact to be zero. This is often referred to as base lining using the "pre-trigger". In this study, the best agreement between calculated displacements and those measured by a fast LVDT resulted from use of the average of the whole acceleration signal after triggering as the baseline. This topic requires additional study.

Problems of non-linearity (even slight non-linearity) and base-line shift during motion measurements, amongst a host of other potential factors, can result in erroneous values of computed velocity. This effect becomes magnified since the computation of FV energy involves a second step of integration after multiplying by the measured force.

Some Pictures of drill rods attached with sensors and graph of SPT analyzer in PDA Machine age given below:



Picture 3.1: Sensors attached with special drill rod



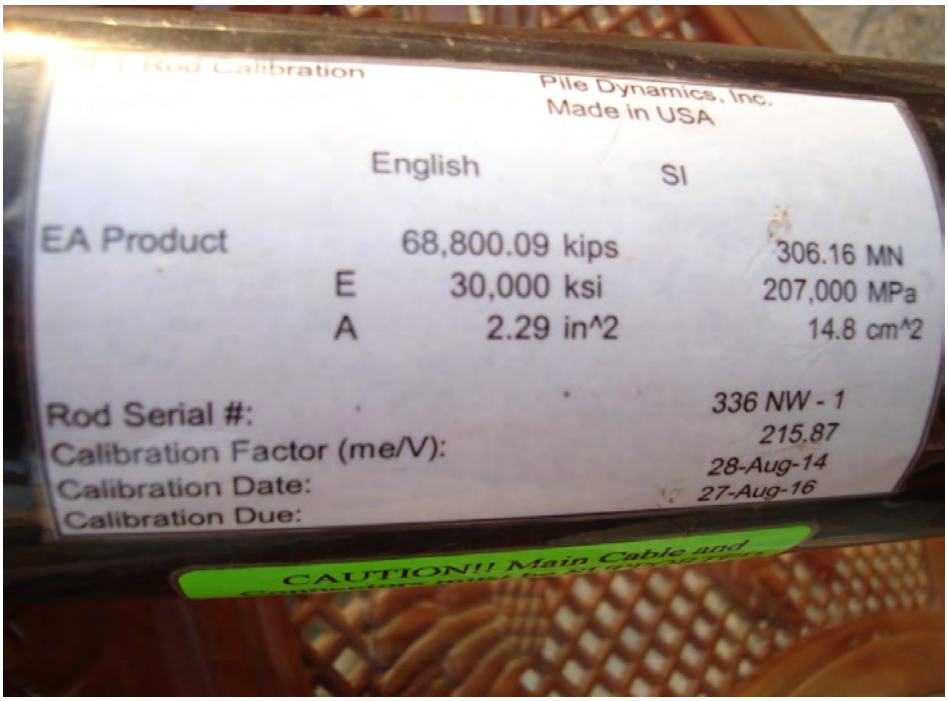
Picture 3.2: Data is received by data cable from sensors



Picture 3.3: Sensors attached with special drill rod



Picture 3.4: Sensors attached with special drill rod



Picture 3.5: Material and cross sectional property of the drill rod



Picture 3.6: Sensors attached with special drill rod



Picture 3.7: Sensors attached with special drill rod



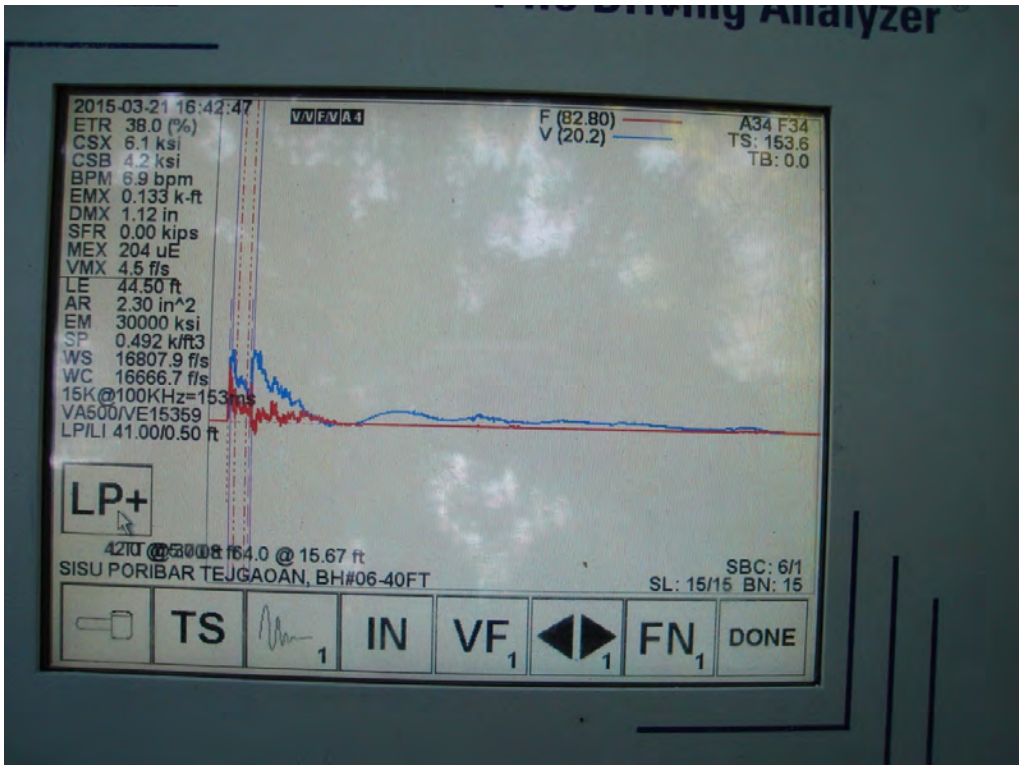
Picture 3.8: The drill rod piece with sensors attached with the main drill rod



Picture 3.9: The drill rod piece with sensors attached with the main drill rod



Picture 3.10: The hammer hits the drill rod and sensor sends information to the system



Picture 3.11: Data from the sensors are fed in this analyzer for calculation

Chapter 4
FIELD TEST PROGRAM

4.1 Testing Location and Equipment Used

The present study was concerned with the transfer of energy to the drill rod during Standard Penetration Test. Sophisticated PDA analyzer was used for the purpose to determine the energy of drop for various site and soil conditions, and to get relationship of 'N' Value by estimating the energy transfer.

The tests were conducted in three selected locations of Dhaka city. The sites were Rajarbag Police Line, Sarkari Shishu Paribar Project, Tejgaon and Business studies faculty of Dhaka University. The locations are indicated in Picture 4.1. Details of test locations are presented in Table 4.1.

At Rajarbag Police Line site, Auto trip Hammer was used. Testing was done in one borehole at a depth of 60 ft to 61 ft and 65 ft to 66 ft.

At Shishu Paribar Tejgaon site, Manual hammer was used which is very common in Bangladesh. Testing was done in one borehole at a depth of 40 ft to 41 ft and 45ft to 46 ft.

At Dhaka University site, Autotrip hammer was used at 55ft and 60 ft level and Manual hammer was used to test at 50 ft, 65 ft and 70 ft. All these tests were conducted in boreholes done by wash boring.

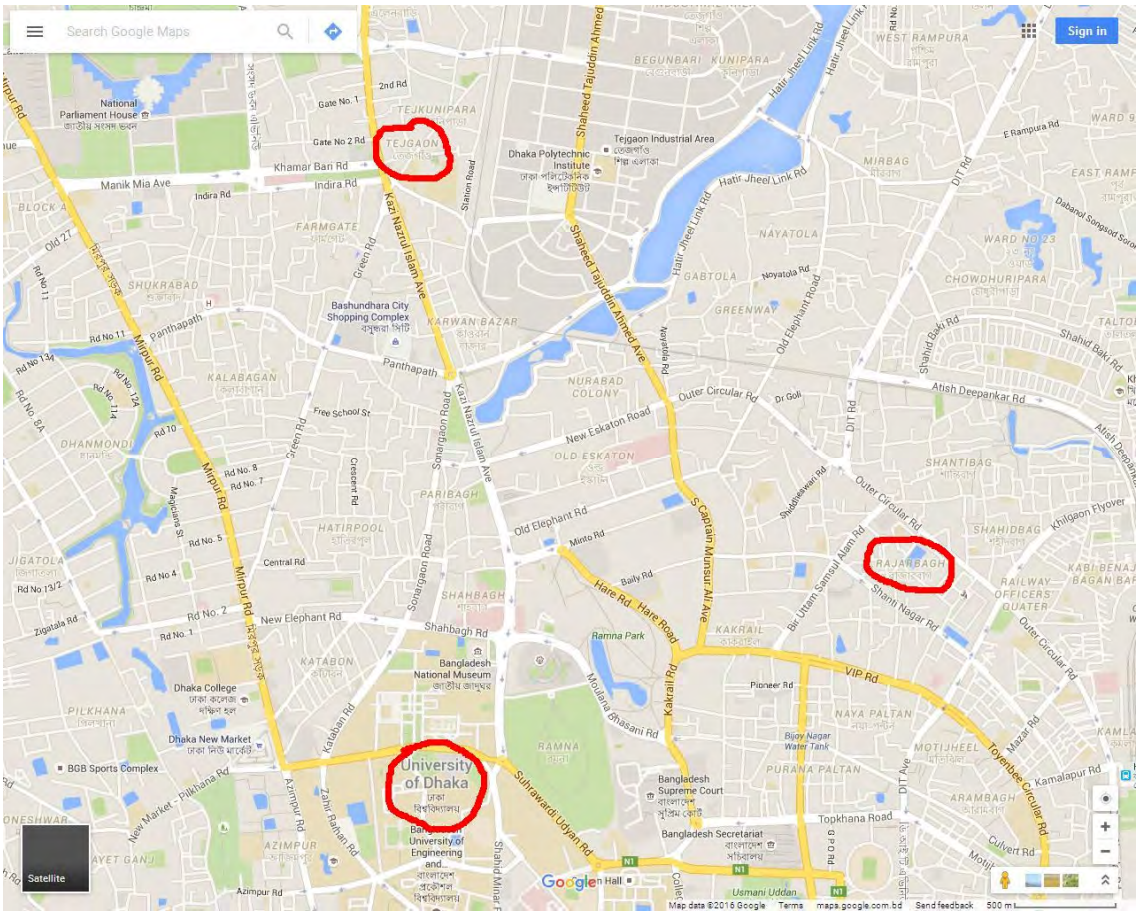
4.2 Test Procedure and Equipment Used

The analyzer recorded each blow. Care was exercised to verify the quality of the readings before proceeding to the next 5 foot depth. Only the blows for the last two 6 inch increments were used in the analysis since these blows correspond to the N value. The rope used was in good condition. No liner was used in the split spoon sampler. The wt of hammer was 140lb and lifted for 30 inch and dropped.

4.2.1 SPT Analyzer

In this work SPT Analyzer was used with PDA Machine. Here 2 feet long NW-1 drill rod section, hand-held unit and the software for use in evaluating the data were used. Foil strain

gauges were glued directly on to the rod to measure strain, which is converted to force by using the cross sectional area and modules of elasticity of the rod. The acceleration measured by the accelerometer is integrated to obtain velocity. The instrumented rod was affixed to the top of the drill string just below the anvil during testing. The unit had an LCD touch-screen for entering rod area and length, descriptions and names and user comments. The beginning of the hammer blow triggered the analyzer to begin recording data. These data were continuously displayed on the screen as the force wave and the velocity wave. The data were saved for a user in the memory of the unit. Raw data and energy related quantities were sorted and downloaded into the computer using PDI software. Pictures (4.1) to (4.9) illustrate the collecting of data using the machine.



Picture 4.1. Map indicating test site locations

Table 4.1 Testing location details.

Site	Type of hammer	No of Borehole	Depth (ft)	Type of soil	SPT (N)
Rajarbag Police Line, Dhaka	Auto	02	60-61	Brown, medium dense to dense, nonplastic, **SILT, ML,** trace of mica	41
Rajarbag Police Line, Dhaka	Auto	02	65-66	Brown , dense, **SILTY SAND, SM,** trace of mica	59
Sarkari Shishu Paribar, Tejgaon, Dhaka	Manual	06	40-41	Brown, medium dense fine **SAND**, little trace mica	23
Sarkari Shishu Paribar, Tejgaon, Dhaka	Manual	06	45-46	Brown, medium dense fine **SAND**, little trace mica	18
Dhaka University	Manual	04	50	Brown, Loose to dense, **Silty SAND, SM,** trace of mica.	33
Dhaka University	Auto	04	55	Brown, Loose to dense, **Silty SAND, SM,** trace of mica.	27
Dhaka University	Auto	04	60	Brown, Loose to dense, **Silty SAND, SM,** trace of mica.	30
Dhaka University	Manual	04	65	Brown, Loose to dense, **Silty SAND, SM,** trace of mica.	40
Dhaka University	Manual	04	70	Brown, Loose to dense, **Silty SAND, SM,** trace of mica.	40



Picture 4.2: SPT by Auto Hammer on Rajarbag Site, Tejgaon



Picture 4.3: SPT by Auto Hammer on Rajarbag Site, Tejgaon



Picture 4.4: SPT by Auto Hammer on Rajarbag Site, Tejgaon



Picture 4.5: SPT by Manual Hammer on Sarkari Shishu Paribar Site, Tejgaon



Picture 4.6: SPT by Manual Hammer on Sarkari Shishu Paribar Site, Tejgaon



Picture 4.7: SPT by Manual Hammer at Business studies Faculty, Dhaka University



Picture 4.8: SPT by Auto trip Hammer at Business studies Faculty, Dhaka University



Picture 4.9: Data acquisition by PDA analyser during SPT

Chapter 5
RESULTS AND DISCUSSIONS

5.1 Data Quality Assessment

Data were downloaded onto a laptop computer and were evaluated for quality and adjusted or excluded as appropriate. Data were reviewed using the PDI program. Each blow from each SPT sample was reviewed and evaluated. The data were evaluated to ensure that all gauges were recording in phase and that all appeared to be returning reasonable readings. The velocity and force curves needed to be shifted to peak simultaneously just beyond the time of impact. Furthermore, it was necessary to check the quality of the data since a number of possible events can adversely affect the quality. One such event is circuit overloading. Loose bolts attaching the accelerometers to the instrumented rod is another.

Example of data received from PDI software is shown in Figure 5.1. These data were used to calculate to energy transfer. The completed test data are presented in APPENDIXA, that includes the time, blow number, EF2, maximum force in the drill rod, maximum velocity of the rod, maximum displacement of the rod, etc.

5.2 Data Reduction

After each hammer blow within a sample was reviewed, bad data from circuit overloading, loose connections or faulty accelerometers were eliminated. Only the hammer blows contributing to the SPT N value were used in the analysis.

Data reduction included calculating the energy transfer ratios for all hammers and calculating standard deviation of the energy transfer ratios to find the variation of energy transfer by two different methods, manual hammer and auto hammer. An average of energy transfer ratios was also calculated to compare auto hammer and manual hammer efficiency with the standard hammer efficiency. From all the data Average Energy Transfer Ratio and standard deviation are calculated and shown in Table 5.1, for both auto trip and manual hammer.

5.3 Effect of SPT Value on Energy Transfer Ratio

Data of Energy Transfer Ratios (ETR) and SPT N value, Table 5.1, suggests that ETR value varies in between 33% to 70% for the hammer used in Bangladesh. Energy Transfer Ratios

are plotted against Standard Penetration Test value in Figure 5.2. They show scattered relationship and reveals that energy transfer ratio does not have any trend with SPT values while considered both the types of hammer. This may be due to the fact that the efficiency of auto trip and manual drop hammer is usually considered to be different. This agrees with the findings of previous investigators that ETR depends on type of hammer. It is an interesting observation that the energy ratio is prominent and in the order of 60-70 percent, in the range of SPT of 25-40. An average value of ETR may be taken as 65% in this range of SPT mentioned (25-40).In the lower SPT range (< 25) and higher range of SPT, the average ETR was found in the order of 35% and 40% respectively. The phenomenon is difficult to explain and may need rigorous study.

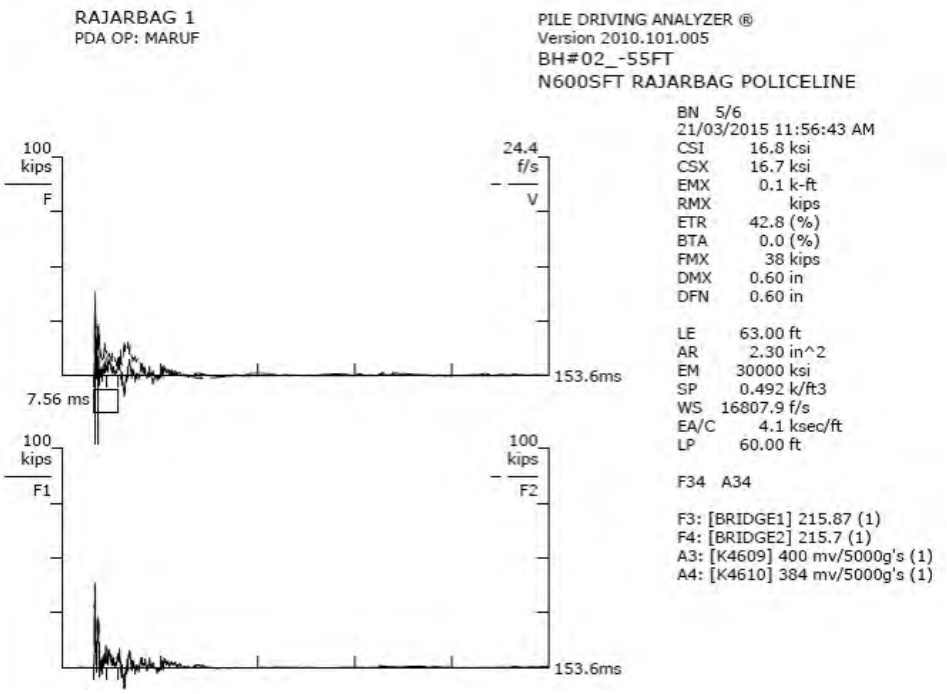


Figure 5.1: Typical velocity and force data as received from the PDI Software

Table 5.1 Average ETR and standard deviation of different hammer systems.

Site	Type of Hammer	SPT	ETR, %	Standard Deviation, %	Drill Rod Length, inch
Rajarbag Police Line, Dhaka.	Auto	41	41.21	3.16	60
	Auto	50	40.14	5.95	65
Sarkari Shishu Paribar, Tejgaon, Dhaka	Manual	23	36.38	5.03	40
	Manual	18	33.42	4.14	45
Business Studies Faculty, Dhaka University.	Manual	33	58.97	6.44	50
	Auto	27	71.00	1.53	55
	Auto	30	71.08	10.21	60
	Manual	40	62.41	7.54	65
	Manual	40	66.07	4.36	70

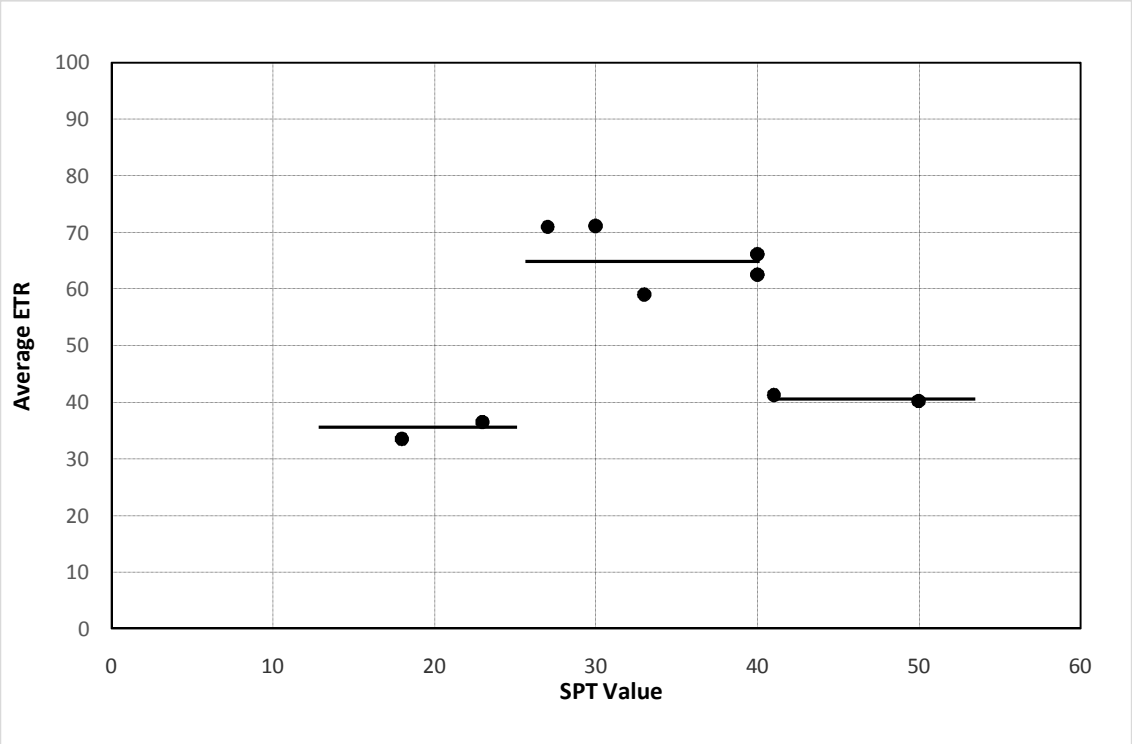


Figure 5.2: Variation of energy transfer ratio with SPT for both auto trip and manual hammer

5.3 Energy Transfer Ratio for Auto Trip Hammer

Data of energy transfer ratio (ETR) and SPT values for the sites where auto trip hammer used are isolated and presented in Table 5.2. Data of ETR are also plotted against SPT values and presented in Figures 5.2a and 5.2b. It was observed that in general ETR decreases with the increase of SPT value, and varies in the range of 40% to 70%.Statistical analysis of the limited data, Figure 5.2a, reveals that there exists good 2nd degree polynomial relationship between SPT value N and ETR with a regression coefficient (r^2) of 0.9449. The relation may be expressed using Equation (5.1). However, further simplification of the data yields that ETR ratio for auto trip hammer only varies in between SPT values approximately 30 to 40 For lower and higher SPT values, ETR remains constant as 70% and 40% respectively. They can be expressed by Equations (5.2a), (5.2b), and (5.2c). Explanation of the phenomenon would require rigorous study and research.

$$ETR = 0.075N^2 - 7.25N + 215 \quad (For\ All\ N) \qquad (5.1)$$

$$ETR = 150 - 2.75N \quad (30 \leq N \leq 40) \qquad (5.2a)$$

$$ETR = 70 \quad (For\ N < 30) \qquad (5.2b)$$

$$ETR = 40 \quad (For\ \ N > 40) \qquad (5.4c)$$

Table 5.2 Average ETR and SPT on autotrip hammer.

Site	SPT	Energy Transfer Ratio (ETR), %	Length of Drill Rod, inch
Rajarbag Police Line, Dhaka.	41	41.21	60
	50	40.14	65
Business Studies Faculty, Dhaka University.	27	71.00	55
	30	71.08	60

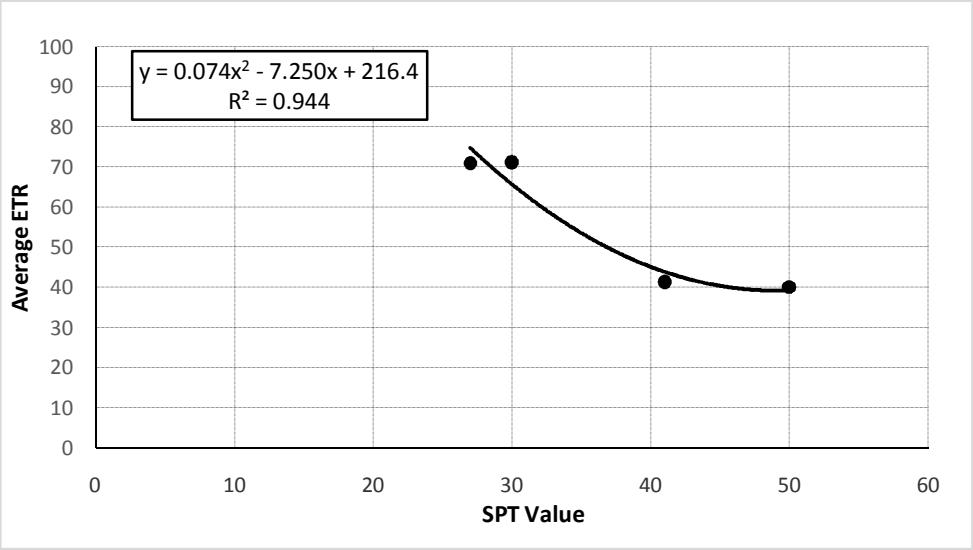


Figure 5.2a: Variation of energy transfer ratio with SPT for auto trip hammer

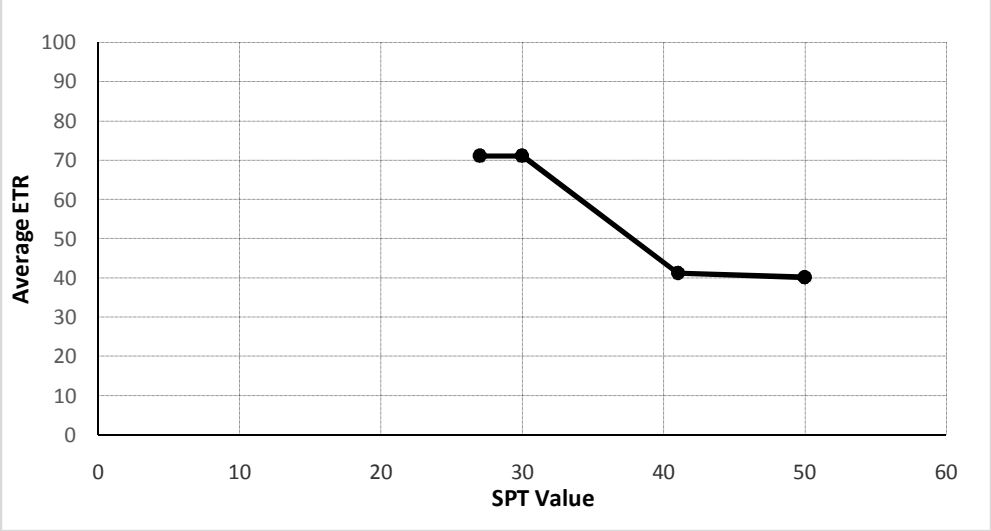


Figure 5.2b: Variation of energy transfer ratio with SPT for auto trip hammer

5.4 Energy Transfer Ratio for Manual Hammer

Similar to that of auto trip hammer, data of energy transfer ratio (ETR) and SPT values for the sites where manual hammer used are isolated and presented in Table 5.3. Data of ETR are also plotted against SPT values and presented in Figures 5.3a and 5.3b.

Contrary to the auto trip hammer, it was observed that in general ETR increases with the increase of SPT value, and varies in the range of 33% to 66%. Statistical analysis of the limited data, Figure 5.3a, reveals that there exists good linear relationship between SPT value N and ETR, with a regression coefficient (r^2) of 0.9583. The relation may be expressed using Equation (5.3). However, further simplification of the data yields that ETR ratio for auto trip hammer only varies in between SPT values approximately 23 to 33. For lower and higher SPT values, ETR remains constant as 35% and 62% respectively. They can be expressed by Equations (5.4a), (5.4b), and (5.4c). Explanation of the phenomenon would require rigorous study and research.

$$ETR = 1.5N + 5.1 \quad (For\ All\ N) \qquad (5.3)$$

$$ETR = 23 - 2.3N \quad (For\ 23 \leq N \leq 33) \qquad (5.4a)$$

$$ETR = 35 \quad (For\ N < 23) \qquad (5.4b)$$

$$ETR = 62 \quad (For\ \ N > 33) \qquad (5.4c)$$

Table 5.3 Average ETR and SPT on manual hammer.

Site	SPT	Energy Transfer Ratio (ETR), %	Length of Drill Rod, inch
Rajarbag Police Line, Dhaka.	23	36.38	40
	18	33.42	45
Business Studies Faculty, Dhaka University.	33	58.97	50
	40	62.41	65
	40	66.07	70

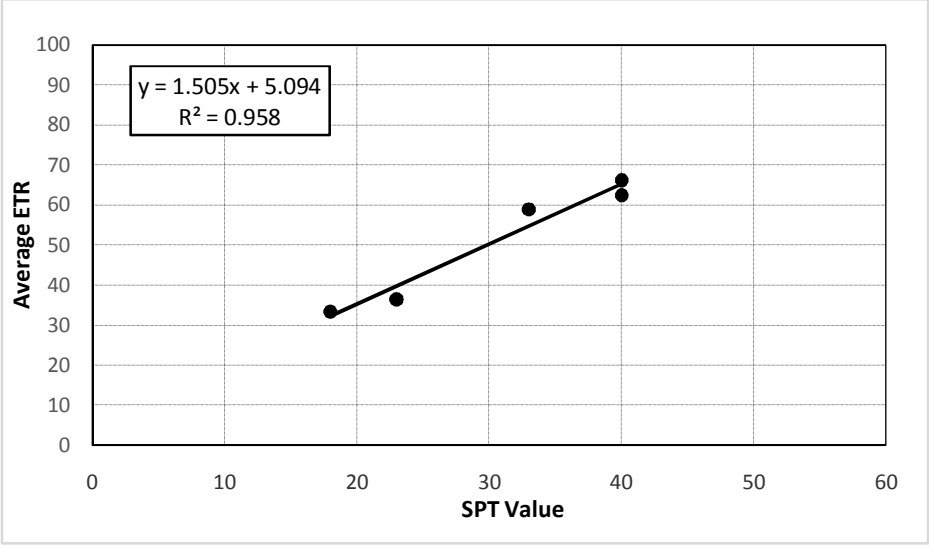


Figure 5.3a: Variation of energy transfer ratio with SPT for manual drop hammer

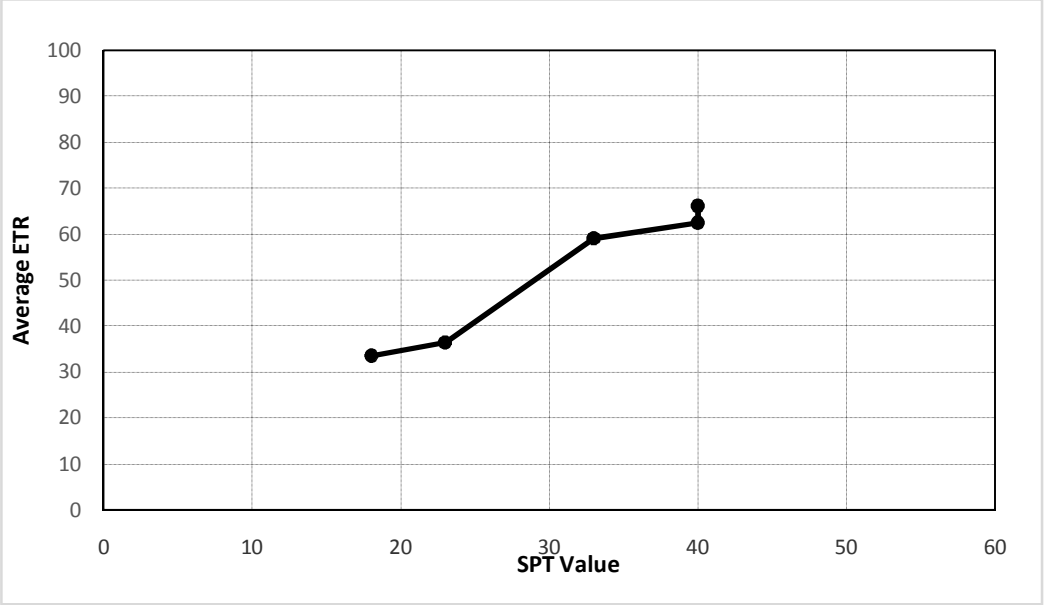


Figure 5.3b: Variation of energy transfer ratio with SPT for manual drop hammer

Chapter 6

CONCLUSION AND RECOMMENDATIONS

6.1 General

The present study was mainly concerned with the energy transfer phenomenon of hammers during Standard Penetration Test. The Standard Penetration Test (SPT) is currently the most popular and economical means of obtaining subsurface information. Although great effort has been put into standardizing the SPT procedure (ASTM D 1586), variability is inherent in present procedures.

The standard penetration resistance is, in fact, conventionally measured using different kinds of hammers, drill rig types, drill rod lengths, drill rod types, hammer blow rates, different energy delivery systems with different degrees of efficiency, different borehole fluids, and different kinds of sampling tubes. Consequently, the consistency of the SPT N values is questioned, i.e., the ability of the test to reproduce blow counts using different drill rig systems under the same site/soil conditions.

In order to reduce the significant variability associated with the SPT N value, it was recommended that N values be standardized to N_{60}. This standardization was to be achieved by correcting the measured field N values by the ratio of that SPT system's energy transfer to the standard 60% energy of a free fall hammer. This requires knowing the performance characteristics of the SPT system.

In this study, SPT energy measurements were made using the Pile Dynamic, Inc. manufactured SPT Analyzer for 2 SPT hammer systems automatic hammer and manual hammer. All tests were performed under field conditions with the normal operating procedure.

6.2 Conclusions

The tests were performed in three selected site locations. The arrangements of the equipment were difficult and the tests were performed in random fashion. No straight forward comparison can be made between these results. For this reason, each test has been taken as individual cases. The following conclusions can be drawn from the present study.

(i) As expected, energy transfer ratio was found to be depended on hammer type. In general ETR is higher (in the range of 70% to 40%) for auto trip hammer as compared to that of manual donut hammer (in the range of 33% to 66%).

(ii) It was an interesting observation that ETR was not constant for a particular hammer, rather varied with SPT N value of the soil layer under test.

(iii) ETR value was found to decrease with increased SPT N value for auto trip hammer. The variation was found prominent in the SPT N range of 30 to 40. For lower and higher SPT values beyond this range ETR values almost remained constant, and observed to be 70% and 40% respectively. The ETR values for auto trip hammer may be estimated using the derived formula given by Equations (5.1), (5.1a), (5.1b) and (5.1c).

(iv) ETR value was found to increase with increased SPT N value for manual hammer. The variation was found prominent in the SPT N range of 23 to 33. For lower and higher SPT values beyond this range ETR values almost remained constant, and observed to be 33% and 66% respectively. The ETR values for auto trip hammer may be estimated using the derived formula given by Equations (5.2), (5.2a), (5.2b) and (5.2c).

6.3 Recommendations for Further Study

The present study was limited to a particular soil type, silty sand. The number of tests was very limited. The depth of SPT was in the range of 45 to 65 ft. In order to generalize the observations of the present study, the following further study may be suggested.

(i) Study may be carried on purely sandy soil and other types of soil as well.

(ii) Study may be carried at similar depths with various types of hammer.

(iii) Further study may be done considering water table.

(iv) Further study should consider diameter of borehole and length of drill rod.

(v) Other energy measuring device may be used in further study.

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Appendix-A

Automatic Hammer

2.3	sq inch	Area
	feet	Length
0.492	feet^3	Specifiq Weight Density
16807.9	ft/sec	Wave speed
30000	ksi	Elastic Modulus

Strain Gauge Calibration Factors
F3 F1(BRIDGE1)
F4 F2(BRIDGE2)

Accelerometer Calibration Factors
A3 K4609
A4 K4610

PROJECT- 600 SFT RAJARBAG POLICE LINE
BOREHOLE-02_55FT
PDA OP-MARUF

DATE	TIME	LP(feet)	N	SL	ETR(%)	EMX(kip/ft.)	VMX(ft/	FMX(kips)	DFN(in.)	Soil Type
21/3/15	11:56:31	60	41	1	42.8	0.1		38	0.81	
21/3/15	11:56:35	60	41	2	42.1	0.1		39	0.74	
21/3/15	11:56:37	60	41	3	29.8	0.1		30	0.47	
21/3/15	11:56:40	60	41	4	40.3	0.1		39	0.53	
21/3/15	11:56:43	60	41	5	42.8	0.1		38	0.6	
21/3/15	11:56:46	60	41	6	42.6	0.1		39	0.52	
21/3/15	11:56:52	60	41	7	41.4	0.1		41	0.05	
21/3/15	11:56:55	60	41	8	42.5	0.1		39	0.47	
21/3/15	11:56:58	60	41	9	30.8	0.1		39	0.29	
21/3/15	11:57:03	60	41	10	40.7	0.1		38	0.25	
21/3/15	11:57:06	60	41	11	42.4	0.1		38	0.68	
21/3/15	11:57:09	60	41	12	42.1	0.1		38	0.64	
21/3/15	11:57:12	60	41	13	43	0.1		38	0.5	
21/3/15	11:57:18	60	41	14	42	0.1		37	0.5	
21/3/15	11:57:22	60	41	15	41.4	0.1		39	0.49	
21/3/15	11:57:25	60	41	16	41.5	0.1		38	0.52	
21/3/15	11:57:31	60	41	17	41.6	0.1		39	-0.16	
21/3/15	11:57:34	60	41	18	42.3	0.1		38	-0.03	Brown,
21/3/15	11:57:37	60	41	19	40.2	0.1		38	-0.13	medium
21/3/15	11:57:40	60	41	20	43.5	0.1		40	0.32	dense to
21/3/15	11:57:44	60	41	21	41.5	0.1		37	-0.08	dense,
21/3/15	11:57:47	60	41	22	39.9	0.1		38	0.29	nonplastic
21/3/15	11:57:50	60	41	23	42	0.1		39	0.3	SILT, ML,
21/3/15	11:57:53	60.5	41	24	41.8	0.1		38	0.32	trace of mica
21/3/15	11:57:56	61	41	25	40.5	0.1		39	0.26	
21/3/15	11:57:59	61	41	26	42.9	0.1		38	0.24	
21/3/15	11:58:02	61	41	27	44.2	0.1		39	0.32	
21/3/15	11:58:05	61	41	28	43.7	0.1		41	0.26	
21/3/15	11:58:08	61	41	29	42	0.1		38	0.26	
21/3/15	11:58:11	61	41	30	40.5	0.1		39	0.28	
21/3/15	11:58:14	61	41	31	43.4	0.1		39	0.33	
21/3/15	11:58:16	61	41	32	42.9	0.1		40	0.32	
21/3/15	11:58:19	61	41	33	42.4	0.1		40	0.3	
21/3/15	11:58:21	61	41	34	42.3	0.1		39	0.28	
21/3/15	11:58:24	61	41	35	42.6	0.1		38	0.33	
21/3/15	11:58:27	61	41	36	41.8	0.1		39	0.29	
21/3/15	11:58:29	61	41	37	31.8	0.1		28	0.18	
21/3/15	11:58:32	61	41	39	43	0.1		39	0.28	
21/3/15	11:58:35	61	41	40	41.7	0.1		39	0.23	

21/3/15	11:58:38	61	41	41	41.8	0.1	38	0.27

Automatic Hammer

PROJECT- 600 SFT RAJARBAG POLICE LINE
BOREHOLE-02_65FT
PDA OP-MARUF

DATE	TIME	LP(feet)	N	SL	ETR(%)	EMX(kip/ft.)	VMX(ft/	FMX(kips)	DFN(in.)	Soil Type
21/3/15	12:40:20	65	50	1	43.8	0.2		39	0.52	
21/3/15	12:40:23	65	50	2	43	0.2		40	0.42	
21/3/15	12:40:25	65	50	3	41.2	0.1		39	0.66	
21/3/15	12:40:30	65	50	4	40.8	0.1		39	0.34	
21/3/15	12:40:33	65	50	5	42.4	0.1		40	0.47	
21/3/15	12:40:35	65	50	6	44	0.2		40	0.52	
21/3/15	12:40:40	65	50	7	40.7	0.1		39	0.39	
21/3/15	12:40:47	65	50	8	46.5	0.2		36	1.02	
21/3/15	12:40:53	65	50	9	41.5	0.1		39	0.14	
21/3/15	12:40:55	65	50	10	40.3	0.1		38	-0.76	
21/3/15	12:40:58	65.5	50	11	41.6	0.1		39	0.32	
21/3/15	12:41:01	65.5	50	12	40.2	0.1		38	0.19	
21/3/15	12:41:03	65.5	50	13	42.1	0.1		39	0.33	
21/3/15	12:41:06	65.5	50	14	40.8	0.1		38	0.18	
21/3/15	12:41:09	65.5	50	15	41.3	0.1		34	0.38	
21/3/15	12:41:11	65.5	50	16	40.3	0.1		39	0.24	
21/3/15	12:41:14	65.5	50	17	41.6	0.1		38	0.19	
21/3/15	12:41:16	65.5	50	18	41.9	0.1		38	0.22	
21/3/15	12:41:19	65.5	50	19	38.9	0.1		37	0.18	
21/3/15	12:41:22	65.5	50	20	41.3	0.1		39	0.22	
21/3/15	12:41:24	65.5	50	21	40.5	0.1		38	0.21	
21/3/15	12:41:27	65.5	50	22	41.6	0.1		39	0.3	
21/3/15	12:41:29	65.5	50	23	40.3	0.1		37	0.15	
21/3/15	12:41:31	65.5	50	24	40.1	0.1		40	0.14	
21/3/15	12:41:36	65.5	50	25	39.5	0.1		38	0.14	
21/3/15	12:41:38	65.5	50	26	40	0.1		38	0.16	
21/3/15	12:41:40	65.5	50	27	28.8	0.1		31	0.06	
21/3/15	12:41:42	65.5	50	28	43.2	0.2		41	0.22	
21/3/15	12:41:45	65.5	50	29	42.4	0.1		39	0.17	Brown, dense, SILTY SAND, SM, trace of mica
21/3/15	12:41:47	65.5	50	30	41.6	0.1		39	0.15	
21/3/15	12:41:49	65.5	50	31	42.4	0.1		40	0.19	
21/3/15	12:41:51	65.5	50	32	41.9	0.1		40	0.28	
21/3/15	12:41:53	66	50	33	42.8	0.1		38	0.16	
21/3/15	12:41:55	66	50	34	41.6	0.1		41	0.2	
21/3/15	12:41:58	66	50	35	41.9	0.1		39	0.15	
21/3/15	12:42:00	66	50	36	42.2	0.1		40	0.1	
21/3/15	12:42:02	66	50	37	34.3	0.1		34	0.07	
21/3/15	12:42:04	66	50	38	40.9	0.1		39	0.17	
21/3/15	12:42:06	66	50	39	41.8	0.1		39	0.17	
21/3/15	12:42:08	66	50	40	42.8	0.1		39	0.14	
21/3/15	12:42:10	66	50	41	42.1	0.1		39	0.18	
21/3/15	12:42:12	66	50	42	41.4	0.1		39	0.16	
21/3/15	12:42:14	66	50	43	32.6	0.1		33	0.04	
21/3/15	12:42:16	66	50	44	43.7	0.2		39	0.2	
21/3/15	12:42:19	66	50	45	42.7	0.1		40	0.11	
21/3/15	12:42:21	66	50	46	41.9	0.1		41	0.12	
21/3/15	12:42:23	66	50	47	41.3	0.1		40	0.06	
21/3/15	12:42:28	66	50	48	40.1	0.1		39	0.13	
21/3/15	12:42:30	66	50	49	40.7	0.1		39	0.08	
21/3/15	12:42:32	66	50	50	41.8	0.1		40	0.32	

21/3/15	12:42:34	66	50	51	40.9	0.1	40	0.15
21/3/15	12:42:36	66	50	52	41.5	0.1	40	0.15
21/3/15	12:42:38	66	50	53	40.6	0.1	38	0.15
21/3/15	12:42:40	66	50	54	40.8	0.1	38	0.11
21/3/15	12:42:43	66	50	55	39.1	0.1	37	0.11
21/3/15	12:42:45	66	50	56	39.9	0.1	39	0.1
21/3/15	12:42:47	66	50	57	41.2	0.1	39	0.13
21/3/15	12:42:49	66	50	58	28.8	0.1	28	0.05
21/3/15	12:42:51	66	50	59	42.1	0.1	40	0.16

Drop Hammer

PROJECT-SHISHU PORIBAR TEJGAON
BOREHOLE-06_40FT
PDA OP-MARUF

DATE	TIME	LP(feet)	N	SL	ETR(%)	EMX(kip/ft.)	VMX(ft/	FMX(kips)	DFN(in.)	Soil Type
21/3/15	16:41:57	40	23	1	30.7	0.1		14	0.85	
21/3/15	16:42:01	40	23	2	32.1	0.1		13	0.89	
21/3/15	16:42:05	40	23	3	43.1	0.2		14	1.64	
21/3/15	16:42:08	40	23	4	41.8	0.1		14	1.26	
21/3/15	16:42:11	40	23	5	41.4	0.1		15	1.22	
21/3/15	16:42:14	40	23	6	32.5	0.1		13	0.81	
21/3/15	16:42:18	40	23	7	30.9	0.1		14	0.51	
21/3/15	16:42:23	40.5	23	8	34.9	0.1		16	0.71	
21/3/15	16:42:26	40.5	23	9	31.1	0.1		14	0.51	
21/3/15	16:42:30	40.5	23	10	33.5	0.1		14	0.55	Brown
21/3/15	16:42:33	40.5	23	11	32.7	0.1		14	0.45	medium
21/3/15	16:42:36	40.5	23	12	43.3	0.2		15	1.51	dense fine
21/3/15	16:42:39	41	23	13	31.2	0.1		15	0.43	SAND, some
21/3/15	16:42:47	41	23	14	38	0.1		14	1.11	little trace
21/3/15	16:42:50	41	23	15	38.4	0.1		16	1.07	mica
21/3/15	16:42:53	41	23	16	44.1	0.2		16	1.36	
21/3/15	16:42:55	41	23	17	45.5	0.2		16	1.52	
21/3/15	16:42:57	41	23	18	40.5	0.1		15	1.14	
21/3/15	16:43:00	41	23	19	38.6	0.1		15	0.83	
21/3/15	16:43:02	41	23	20	35	0.1		15	0.71	
21/3/15	16:43:04	41	23	21	35.6	0.1		15	0.46	
21/3/15	16:43:07	41	23	22	29.6	0.1		13	0.43	
21/3/15	16:43:09	41	23	23	32.3	0.1		13	0.39	

Drop Hammer

PROJECT-SHISHU PORIBAR TEJGAON
BOREHOLE-06_45FT
PDA OP-MARUF

DATE	TIME	LP(feet)	N	SL	ETR(%)	EMX(kip/ft.)	VMX(ft/	FMX(kips)	DFN(in.)	Soil Type
21/3/15	17:09:52	45	18	1	33.8	0.1		12	0.99	
21/3/15	17:09:53	45	18	2	41.8	0.1		15	1.1	
21/3/15	17:09:55	45	18	3	33.1	0.1		12	0.53	
21/3/15	17:09:56	45	18	4	41.8	0.1		22	1.18	
21/3/15	17:09:58	45	18	5	37.7	0.1		16	0.8	
21/3/15	17:09:59	45	18	6	33.2	0.1		13	0.91	
21/3/15	17:10:00	45	18	7	34.5	0.1		15	0.94	Brown
21/3/15	17:10:02	45	18	8	32.1	0.1		13	0.68	medium
21/3/15	17:10:03	45.5	18	9	30.5	0.1		13	0.46	dense fine
21/3/15	17:10:05	45.5	18	10	32	0.1		15	0.66	SAND, some
21/3/15	17:10:06	45.5	18	11	28.5	0.1		12	0.74	little trace

21/3/15	17:10:08	45.5	18	12	26.6	0.1	11	0.43	mica
21/3/15	17:10:09	45.5	18	13	27.8	0.1	11	0.52	
21/3/15	17:10:11	45.5	18	14	34.1	0.1	14	0.72	
21/3/15	17:10:12	45.5	18	15	37.1	0.1	13	1.03	
21/3/15	17:10:14	45.5	18	16	32.2	0.1	13	0.92	
21/3/15	17:10:15	45.5	18	17	32.2	0.1	11	0.71	
21/3/15	17:10:17	46	18	18	32.6	0.1	14	0.67	

Automatic Hammer

PROJECT-SANARPARA, NARAYANGONJ
BOREHOLE-06_45FT
PDA OP-MARUF

DATE	TIME	LP(feet)	N	SL	ETR(%)	EMX(kip/ft.)	VMX(ft/	FMX(kips)	DFN(in.)	Soil Type
5/23/2015	1:13:41	10		1	60.7	0.2		33	3	
5/23/2015	1:13:51	10		2	63.9	0.2		38	2.89	
5/23/2015	1:13:56	10		3	80.7	0.3		37	3.37	
5/23/2015	1:13:59	10		4	73.1	0.3		42	2.97	
5/23/2015	1:14:03	10		5	80	0.3		41	3.03	
5/23/2015	1:14:07	10		6	77.7	0.3		39	2.78	
5/23/2015	1:14:11	10		8	73.4	0.3		39	2.48	
5/23/2015	1:29:50	20		9	58.4	0.2		40	4.8	
5/23/2015	1:41:04	20		10	58.4	0.2		39	4.01	
5/23/2015	1:41:08	20		11	63.7	0.2		39	4.36	
5/23/2015	1:41:12	20		12	66.5	0.2		40	4.47	
5/23/2015	1:41:16	20		13	63.5	0.2		41	4.4	
5/23/2015	1:53:37	25		14	74.2	0.3		41	4.36	
5/23/2015	1:53:42	25		15	59.8	0.2		41	3.04	
5/23/2015	1:53:46	25		16	72.2	0.3		40	3.71	
5/23/2015	1:53:51	25		17	71.4	0.2		41	3.41	
5/23/2015	1:53:55	30		18	64.9	0.2		40	3.08	
5/23/2015	2:08:12	30		19	72.8	0.3		41	2.96	

Drop Hammer

PROJECT-20 Storied building in Business Studies Faculty, Dhaka University
BOREHOLE-04_50FT
PDA OP-JIHAN

DATE	TIME	LP(feet)	N	SL	ETR(%)	EMX(kip/ft.)	VMX(ft/	FMX(kips)	DFN(in.)	Soil Type
6/12/2015	11.56.02	55	33	1	42.35					
	11.56.09	55		2	57.68					
	11.56.36	55		3	61.39					
	11.56.48	55		4	56.17					
	12.00.01	55		5	57.81					
	12.00.03	55		6	57.38					
	12.00.05	55		7	58.01					
	12.00.07	55		8	56.03					
	12.00.09	55		10	52.47					
	12.00.12	55		11	47.37					
	12.00.14	55		12	50.01					
	12.00.16	55		13	87.47					
	12.02.15	55		14	55.92					
	12.02.17	55		15	59.4					
	12.02.19	55		16	53.98					
	12.02.21	55		17	59.13					
	12.02.23	55		18	64.03					

12.02.25	55	19	61.46		
12.02.27	55	20	64.1		
12.02.29	55	21	58.4		
12.02.32	55	22	55.55		
12.02.34	55	23	56.14		Brown, loose to dense, **Silty SAND, SM**, trace of mica
12.02.36	55	24	62.37		
12.02.38	55	25	51.67		
12.02.41	55	26	58.55		
12.02.43	55	27	57.1		
12.02.45	55	28	57.65		
12.02.47	55	29	58.27		
12.02.50	55	30	55.8		
12.02.52	55	31	59.49		
12.02.54	55	32	52.95		
12.02.57	55	33	62.4		
12.02.59	55	34	59.3		
12.03.01	55	35	60.1		
12.03.03	55	36	68.38		
12.03.06	55	37	65.2		
12.03.08	55	38	62.82		
12.03.10	55	39	58.62		
12.03.13	55	40	58.31		
12.03.15	55	41	63.42		
12.03.18	55	42	59.53		
12.03.20	55	43	63.91		
12.03.22	55	44	60.96		
12.03.25	55	45	54.8		
12.03.28	55	46	64.75		
12.03.31	55	47	67.92		
12.03.33	55	48	55.1		

Automatic Hammer

PROJECT-20 Storied building in Business Studies Faculty, Dhaka University
BOREHOLE-04_55FT
PDA OP-JIHAN

DATE	TIME	LP(feet)	N	SL	ETR(%)	EMX(kip/ft.)	VMX(ft/	FMX(kips)	DFN(in.)	Soil Type
6/12/2015	1.29.15	60	27		70.3	0.3				
	1.29.28	60			72.37					
	1.29.45	60			71.24					Brown, loose to dense, **Silty SAND, SM,** trace of mica
	1.29.50	60			69.22					
	1.29.58	60			72.19					
	1.30.02	60			71.2					
	1.30.10	60			68.09					
	1.31.07	60			71.95					
	1.31.10	60			72.52					

Automatic Hammer

PROJECT-20 Storied building in Business Studies Faculty, Dhaka University
BOREHOLE-04_60FT
PDA OP-JIHAN

DATE	TIME	LP(feet)	N	SL	ETR(%)	EMX(kip/ft.)	VMX(ft/	FMX(kips)	DFN(in.)	Soil Type
6/12/2015	2.05.30	65	30		76.54	0.3				
	2.05.38	65			71.45					
	2.05.42	65			27.61					
	2.05.49	65			72.61					

2.05.53	65	71.02	
2.05.56	65	71.48	
2.06.00	65	75.6	
2.06.03	65	73.53	
2.06.06	65	74.8	
2.06.10	65	50.43	
2.06.13	65	76.48	
2.06.17	65	71.61	
2.06.22	65	74.74	
2.06.25	65	74.95	
2.06.29	65	71.86	
2.06.32	65	76.09	
2.06.35	65	75.84	Brown, loose to dense, **Silty SAND, SM**, trace of mica
2.06.43	65	75.62	
2.06.46	65	75.16	
2.06.49	65	74.13	
2.06.53	65	72.95	
2.06.56	65	74.33	
2.07.00	65	74.66	
2.07.03	65	74.43	
2.07.06	65	47.87	
2.07.09	65	74.96	
2.07.12	65	74.44	
2.07.19	65	74.89	
2.07.22	65	73.82	
2.07.25	65	74.32	
2.07.28	65	80.83	
2.07.31	65	74.49	
2.07.35	65	73.17	
2.07.38	65	72.82	
2.07.41	65	52.99	
2.07.44	65	76.67	

Drop Hammer

PROJECT-20 Storied building in Business Studies Faculty, Dhaka University
BOREHOLE-04_65FT
PDA OP-JIHAN

DATE	TIME	LP(feet)	N	SL	ETR(%)	EMX(kip/ft.)	VMX(ft/	FMX(kips)	DFN(in.)	Soil Type
6/12/2015	2.47.49	70	40		29.97	0.2				
	2.47.56	70			52.42					
	2.47.59	70			57.07					
	2.48.01	70			67.46					
	2.48.04	70			65.63					
	2.48.06	70			64.69					
	2.48.09	70			57.82					
	2.48.11	70			62.62					
	2.48.14	70			64.25					
	2.48.16	70			66.86					
	2.48.19	70			64.2					
	2.48.22	70			53.85					
	2.48.27	70			61					
	2.48.30	70			61.13					
	2.48.32	70			62.98					
	2.48.35	70			62.13					

2:48:38	70	65.54	
2:48:40	70	61.38	
2:48:43	70	67.65	
2:48:45	70	64.38	
2:48:47	70	76.75	
2:48:49	70	87.58	
2:48:50	70	78.62	
2:48:54	70	52.98	Brown, loose to dense, **Silty SAND, SM**, trace of mica
2:48:56	70	62.53	
2:48:59	70	57.98	
2:49:01	70	59.8	
2:49:04	70	62.59	
2:49:06	70	60.35	
2:49:09	70	60.06	
2:49:11	70	60.28	
2:49:14	70	59.83	
2:49:16	70	67.73	
2:49:19	70	62.86	
2:49:21	70	59.12	
2:49:24	70	59.65	
2:49:26	70	61.23	
2:49:28	70	66.27	
2:49:31	70	59.9	
2:49:33	70	68.72	
2:49:35	70	66.28	
2:49:38	70	63.33	
2:49:40	70	64.59	
2:49:43	70	59.94	
2:49:45	70	62.12	
2:49:48	70	64.13	
2:49:50	70	59.72	
2:49:53	70	60.05	
2:49:56	70	59.21	
2:49:58	70	63.3	

Drop Hammer

PROJECT-20 Storied building in Business Studies Faculty, Dhaka University
BOREHOLE-04_70FT
PDA OP-JIHAN

DATE	TIME	LP(feet)	N	SL	ETR(%)	EMX(kip/ft.)	VMX(ft/	FMX(kips)	DFN(in.)	Soil Type
6/12/2015	3:22:07	70	40		58.65	0.2				
	3:22:10	70			68.22					
	3:22:12	70			64.49					
	3:22:15	70			68.7					
	3:22:17	70			68.64					
	3:22:19	70			66.79					
	3:22:22	70			63.94					
	3:22:24	70			61.46					
	3:22:27	70			66.22					
	3:22:31	70			71.75					
	3:22:32	70			69.25					
	3:22:35	70			65.05					
	3:22:37	70			64.34					
	3:22:40	70			69.39					
	3:22:42	70			64.03					

3:22:45	70	62.25
3:22:47	70	59.09
3:22:50	70	56.05
3:22:52	70	62.42
3:22:55	70	74.77
3:22:57	70	66.74
3:22:59	70	65.63
3:23:02	70	59.92
3:23:04	70	66.07
3:23:07	70	59.84
3:23:10	70	70.56
3:23:12	70	65.74
3:23:15	70	59.83
3:23:17	70	70.22
3:23:20	70	65.5
3:23:22	70	64.34
3:23:25	70	62.18
3:23:28	70	65.64
3:23:30	70	64.22
3:23:33	70	63.63
3:23:35	70	68.49
3:23:38	70	61.33
3:23:40	70	69.92
3:23:43	70	67.75
3:23:46	70	66.36
3:23:48	70	63.79
3:23:51	70	73.84
3:23:53	70	69.6
3:23:56	70	70.66
3:23:58	70	64
3:24:01	70	73.13
3:24:03	70	66.02
3:24:06	70	71.19
3:24:08	70	76.59
3:24:11	70	65.52

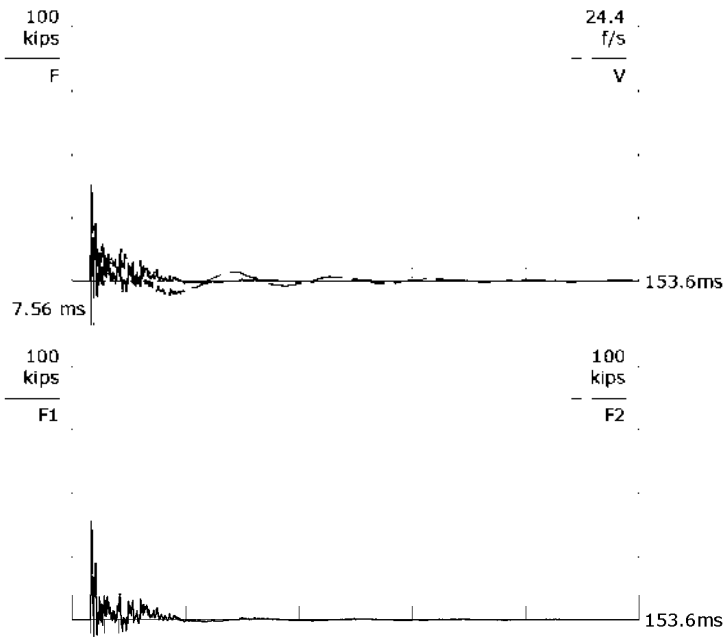
Brown, loose to dense, **Silty SAND, SM**, trace of mica

Appendix-B

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 0/44
21/03/2015 11:58:38 AM
CSI 17.0 ksi
CSX 16.6 ksi
EMX 0.1 k-ft
RMX kips
ETR 41.8 (%)
BTA 0.0 (%)
FMX 38 kips
DMX 0.31 in
DFN 0.27 in

LE 63.00 ft
AR 2.30 in^2
EM 30000 ksi
SP 0.492 k/ft3
WS 16807.9 f/s
EA/C 4.1 ksec/ft
LP 61.50 ft

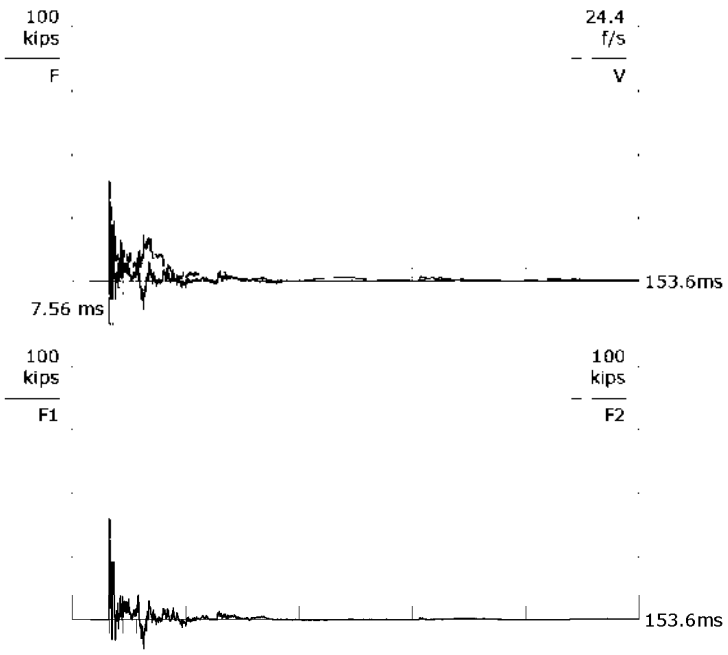
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 2/3
21/03/2015 11:56:35 AM

CSI	17.4 ksi
CSX	17.1 ksi
EMX	0.1 k-ft
RMX	kips
ETR	42.1 (%)
BTA	0.0 (%)
FMX	39 kips
DMX	0.74 in
DFN	0.74 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

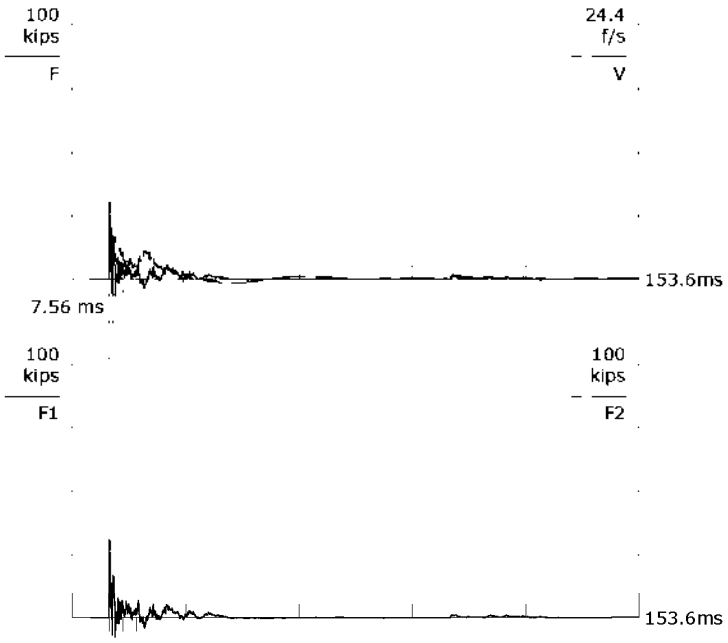
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 3/4
21/03/2015 11:56:37 AM

CSI	13.5 ksi
CSX	13.1 ksi
EMX	0.1 k-ft
RMX	kips
ETR	29.8 (%)
BTA	0.0 (%)
FMX	30 kips
DMX	0.47 in
DFN	0.47 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

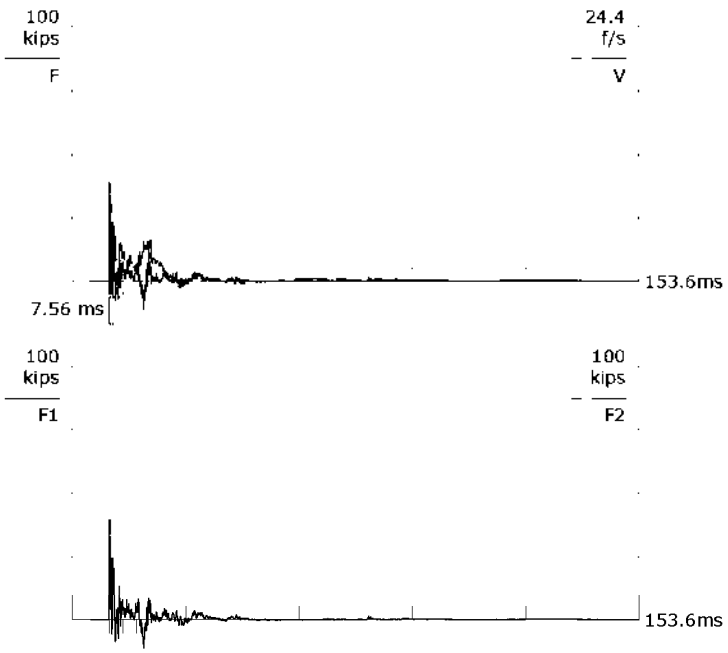
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 4/5
21/03/2015 11:56:40 AM

CSI	17.3 ksi
CSX	17.0 ksi
EMX	0.1 k-ft
RMX	kips
ETR	40.3 (%)
BTA	0.0 (%)
FMX	39 kips
DMX	0.53 in
DFN	0.53 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

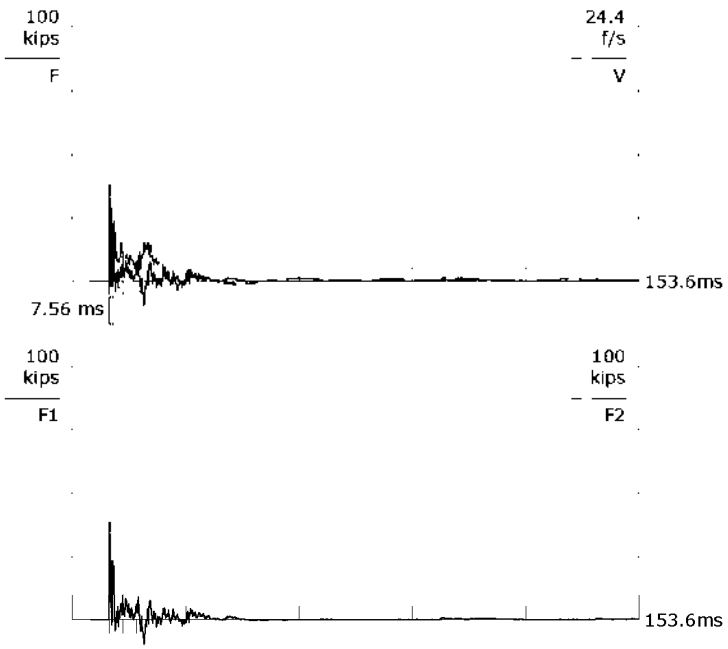
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 5/6
21/03/2015 11:56:43 AM

CSI	16.8 ksi
CSX	16.7 ksi
EMX	0.1 k-ft
RMX	kips
ETR	42.8 (%)
BTA	0.0 (%)
FMX	38 kips
DMX	0.60 in
DFN	0.60 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

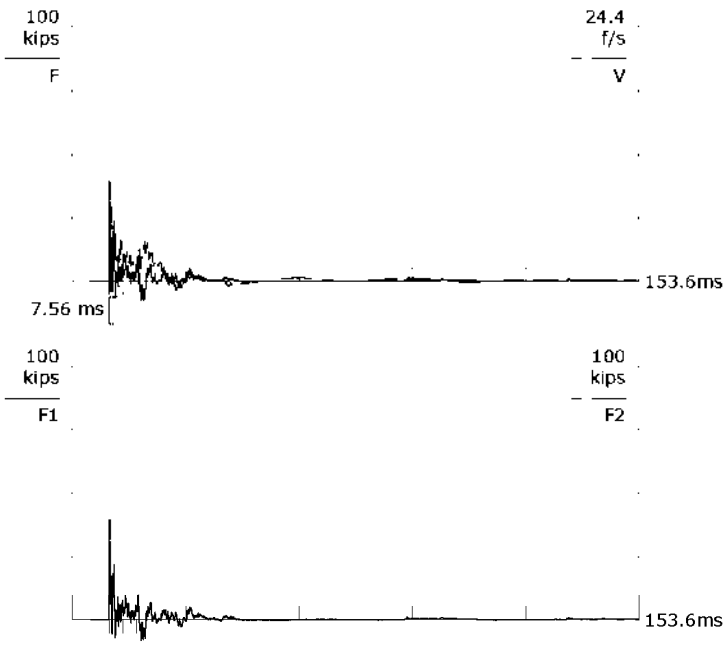
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 6/7
21/03/2015 11:56:46 AM

CSI	17.3 ksi
CSX	17.1 ksi
EMX	0.1 k-ft
RMX	kips
ETR	42.6 (%)
BTA	0.0 (%)
FMX	39 kips
DMX	0.52 in
DFN	0.52 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

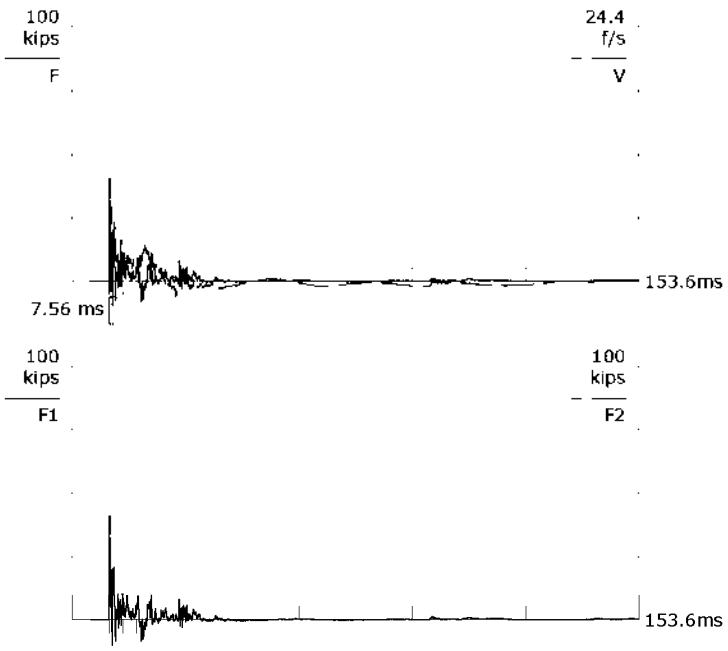
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 8/9
21/03/2015 11:56:52 AM

CSI	17.9 ksi
CSX	17.6 ksi
EMX	0.1 k-ft
RMX	kips
ETR	41.4 (%)
BTA	0.0 (%)
FMX	41 kips
DMX	0.39 in
DFN	0.05 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

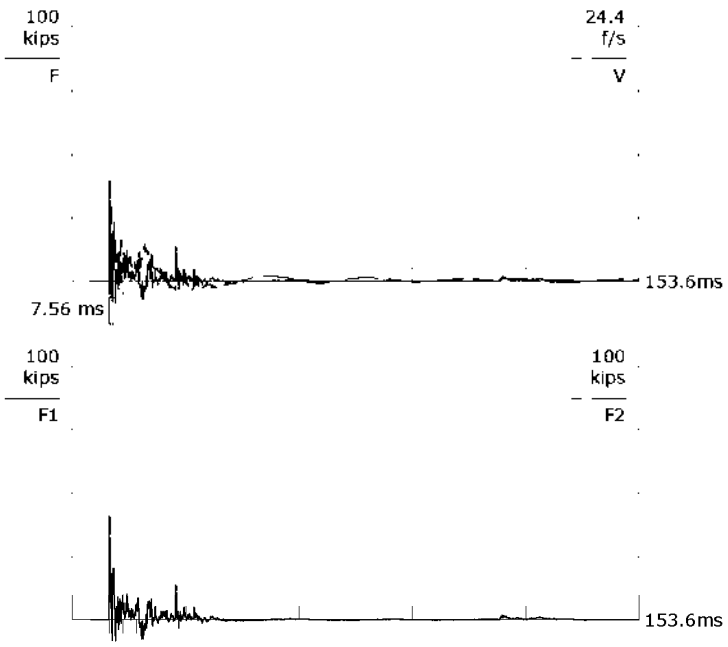
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 9/10
21/03/2015 11:56:55 AM

CSI	17.7 ksi
CSX	17.2 ksi
EMX	0.1 k-ft
RMX	kips
ETR	42.5 (%)
BTA	0.0 (%)
FMX	39 kips
DMX	0.47 in
DFN	0.47 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

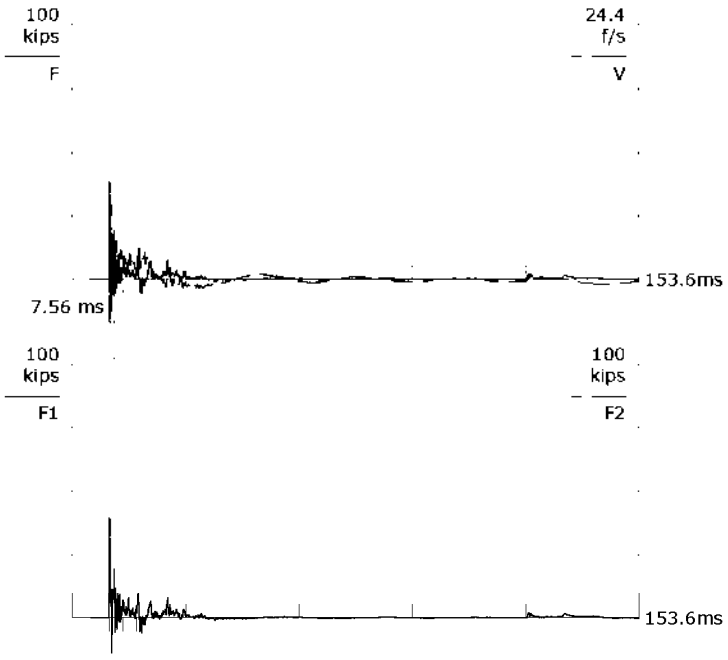
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 10/11
21/03/2015 11:56:58 AM

CSI	17.2 ksi
CSX	16.8 ksi
EMX	0.1 k-ft
RMX	kips
ETR	30.8 (%)
BTA	0.0 (%)
FMX	39 kips
DMX	0.29 in
DFN	0.11 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

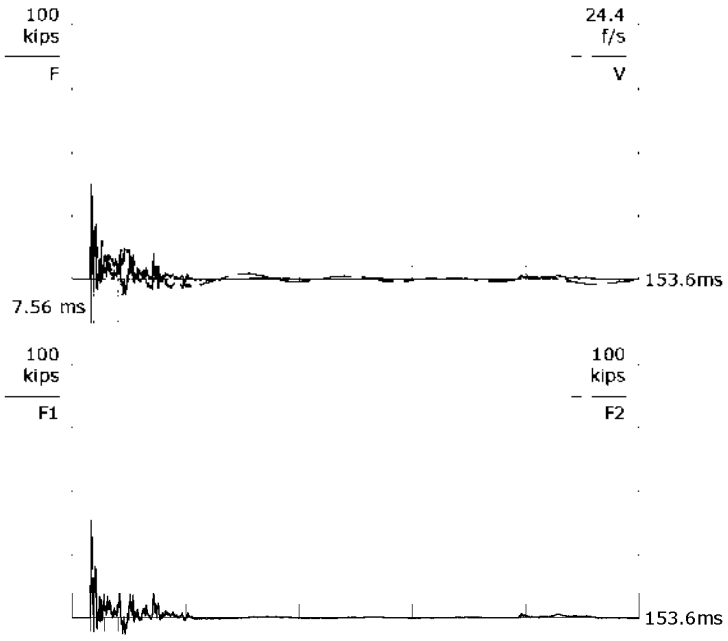
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 11/12
21/03/2015 11:57:03 AM

CSI	16.8 ksi
CSX	16.4 ksi
EMX	0.1 k-ft
RMX	kips
ETR	40.7 (%)
BTA	0.0 (%)
FMX	38 kips
DMX	0.36 in
DFN	0.25 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

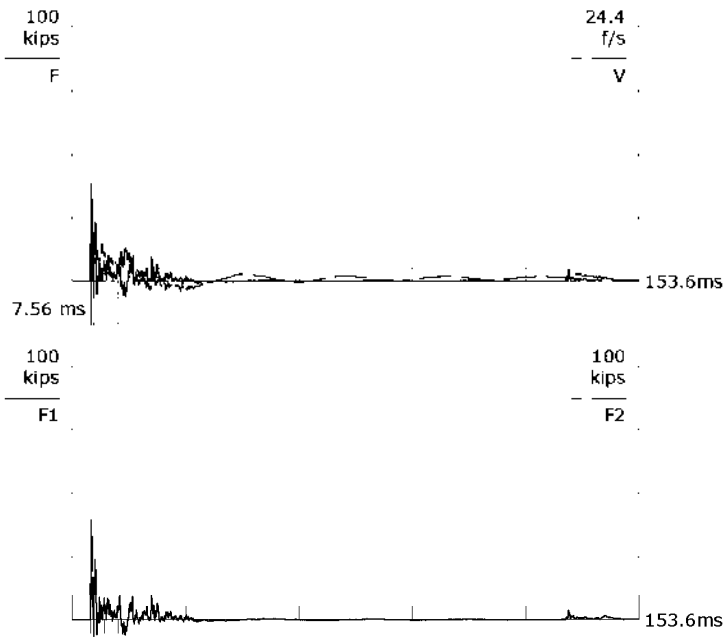
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 12/13
21/03/2015 11:57:06 AM
CSI 17.2 ksi
CSX 16.7 ksi
EMX 0.1 k-ft
RMX kips
ETR 42.4 (%)
BTA 0.0 (%)
FMX 38 kips
DMX 0.68 in
DFN 0.68 in

LE 63.00 ft
AR 2.30 in^2
EM 30000 ksi
SP 0.492 k/ft3
WS 16807.9 f/s
EA/C 4.1 ksec/ft
LP 60.00 ft

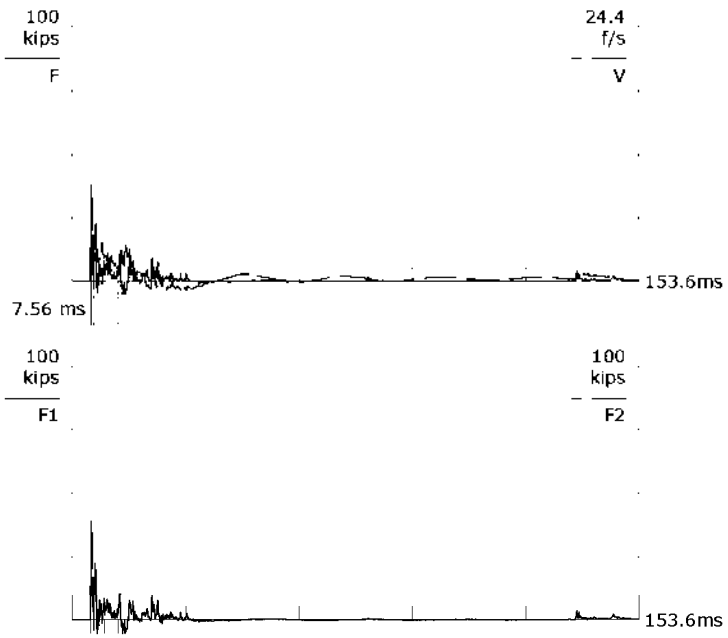
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 13/14
21/03/2015 11:57:09 AM

CSI	17.0 ksi
CSX	16.6 ksi
EMX	0.1 k-ft
RMX	kips
ETR	42.1 (%)
BTA	0.0 (%)
FMX	38 kips
DMX	0.64 in
DFN	0.64 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

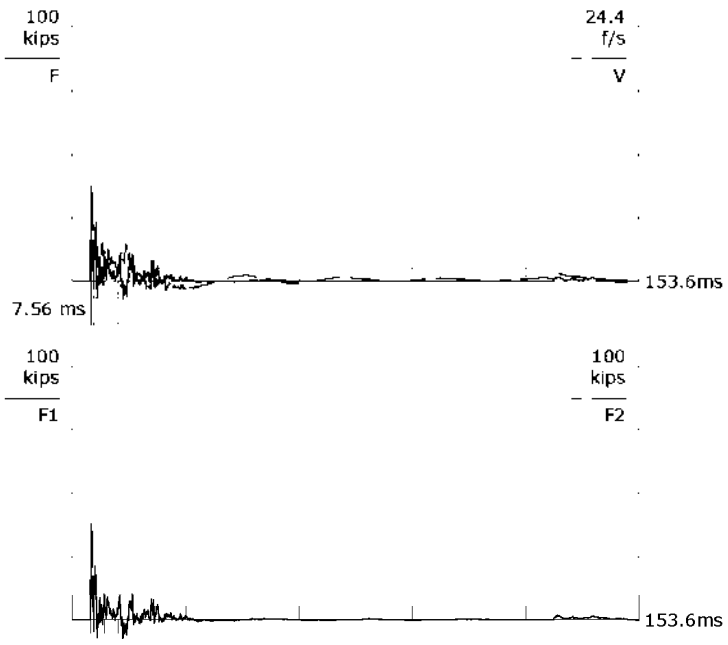
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 14/15
21/03/2015 11:57:12 AM

CSI	16.6 ksi
CSX	16.3 ksi
EMX	0.2 k-ft
RMX	kips
ETR	43.0 (%)
BTA	0.0 (%)
FMX	38 kips
DMX	0.51 in
DFN	0.50 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

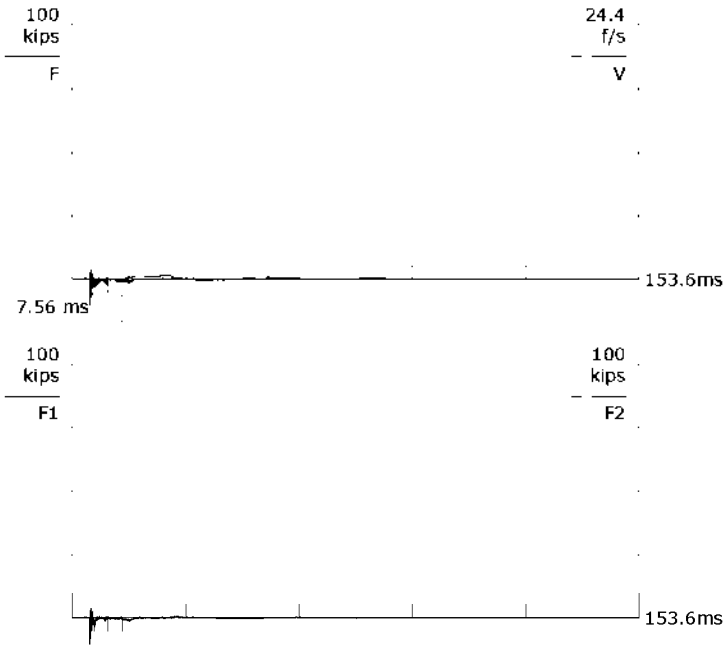
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 15/16
21/03/2015 11:57:15 AM

CSI	1.5 ksi
CSX	1.5 ksi
EMX	0.0 k-ft
RMX	kips
ETR	0.9 (%)
BTA	100.0 (%)
FMX	3 kips
DMX	0.03 in
DFN	0.03 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

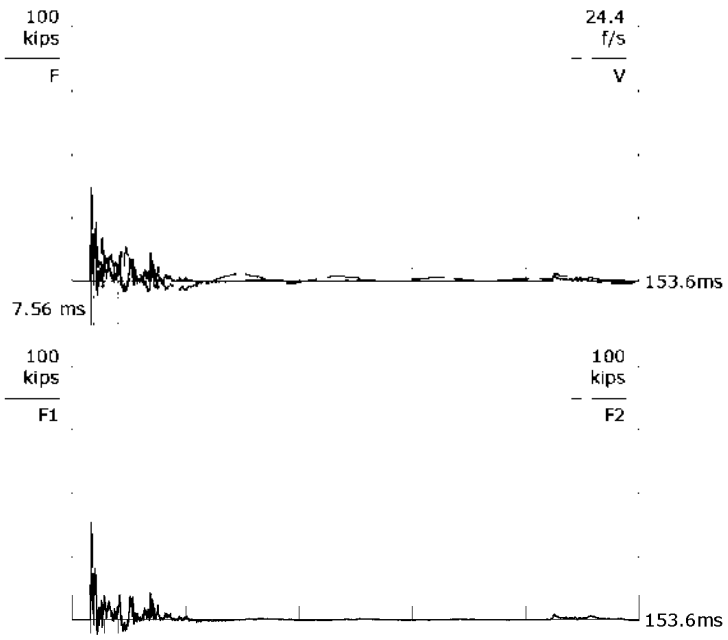
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 16/17
21/03/2015 11:57:18 AM

CSI	16.8 ksi
CSX	16.1 ksi
EMX	0.1 k-ft
RMX	kips
ETR	42.0 (%)
BTA	0.0 (%)
FMX	37 kips
DMX	0.53 in
DFN	0.50 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

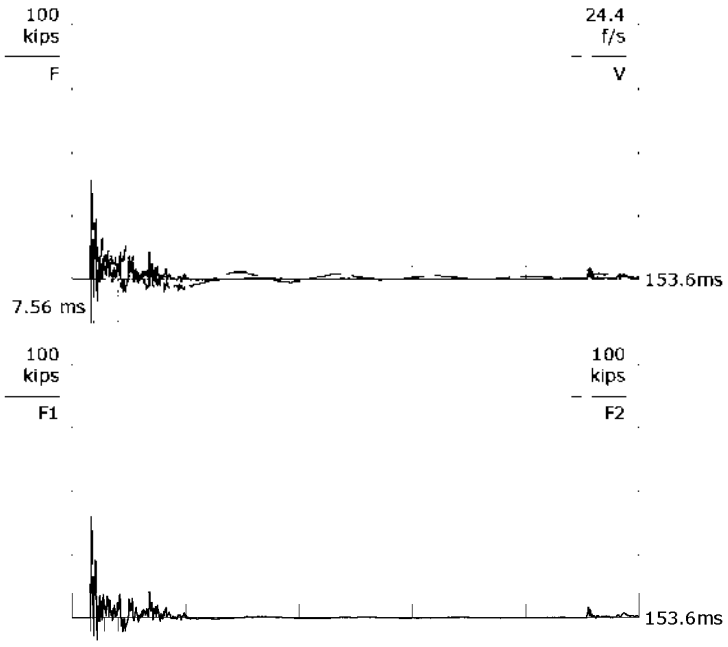
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 17/18
21/03/2015 11:57:22 AM

CSI	17.5 ksi
CSX	17.0 ksi
EMX	0.1 k-ft
RMX	kips
ETR	41.4 (%)
BTA	0.0 (%)
FMX	39 kips
DMX	0.49 in
DFN	0.49 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

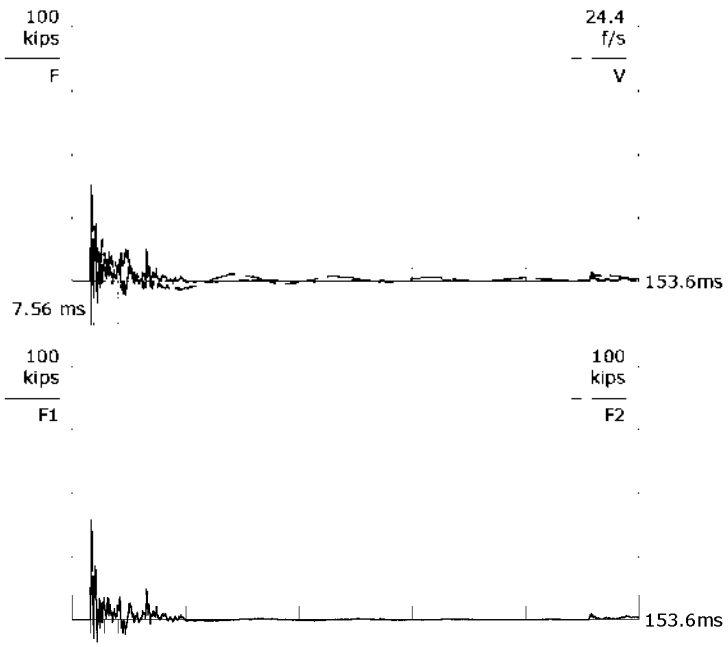
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 18/19
21/03/2015 11:57:25 AM

CSI	17.2 ksi
CSX	16.6 ksi
EMX	0.1 k-ft
RMX	kips
ETR	41.5 (%)
BTA	0.0 (%)
FMX	38 kips
DMX	0.52 in
DFN	0.52 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

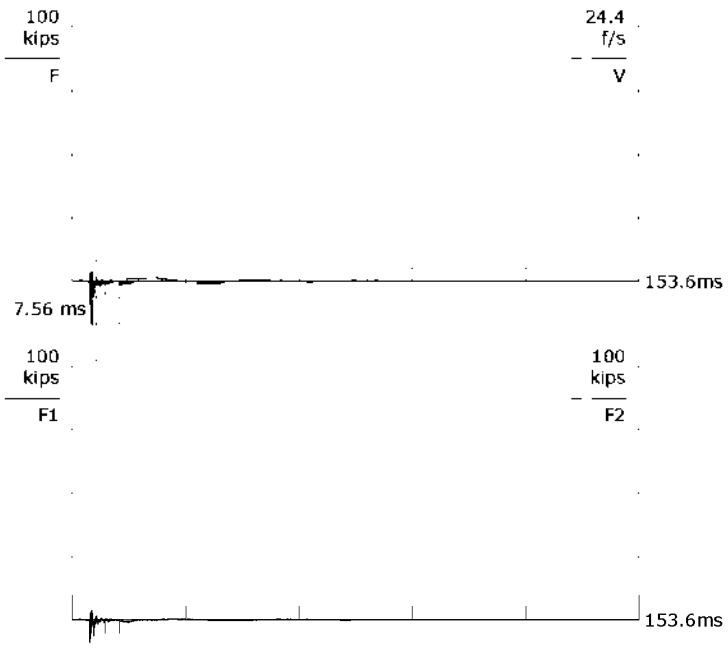
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 19/20
21/03/2015 11:57:27 AM

CSI	1.7 ksi
CSX	1.5 ksi
EMX	0.0 k-ft
RMX	kips
ETR	0.9 (%)
BTA	0.0 (%)
FMX	4 kips
DMX	0.00 in
DFN	-0.02 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

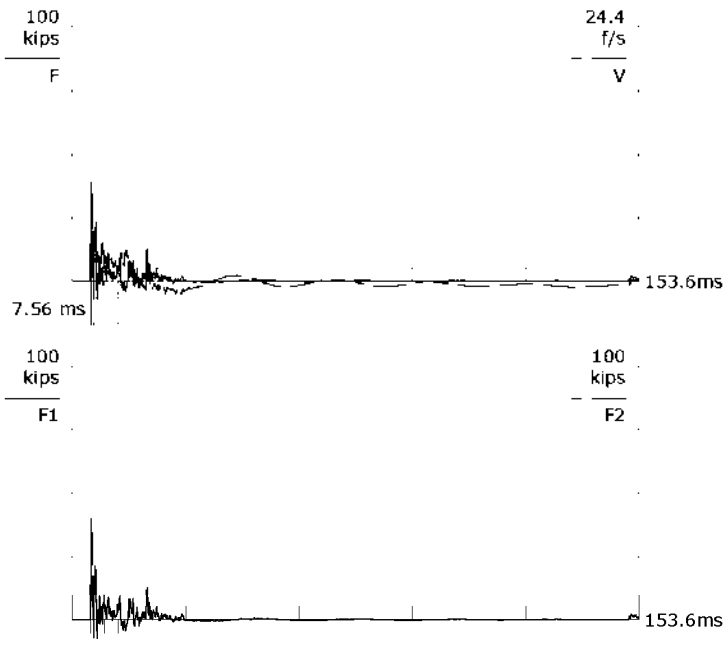
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 20/21
21/03/2015 11:57:31 AM

CSI	17.4 ksi
CSX	17.0 ksi
EMX	0.1 k-ft
RMX	kips
ETR	41.6 (%)
BTA	0.0 (%)
FMX	39 kips
DMX	0.32 in
DFN	-0.16 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

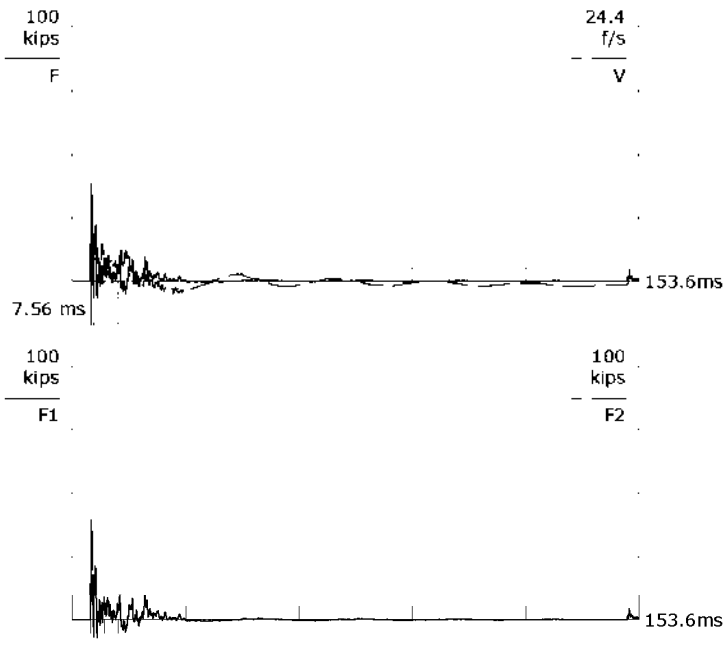
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 21/22
21/03/2015 11:57:34 AM

CSI	17.3 ksi
CSX	16.7 ksi
EMX	0.1 k-ft
RMX	kips
ETR	42.3 (%)
BTA	0.0 (%)
FMX	38 kips
DMX	0.32 in
DFN	-0.03 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

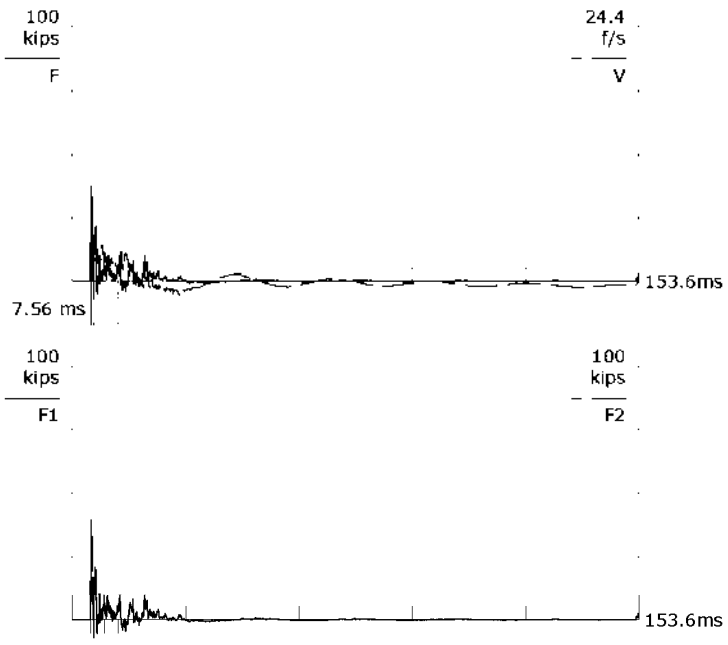
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 22/23
21/03/2015 11:57:37 AM

CSI	17.2 ksi
CSX	16.4 ksi
EMX	0.1 k-ft
RMX	kips
ETR	40.2 (%)
BTA	0.0 (%)
FMX	38 kips
DMX	0.31 in
DFN	-0.13 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

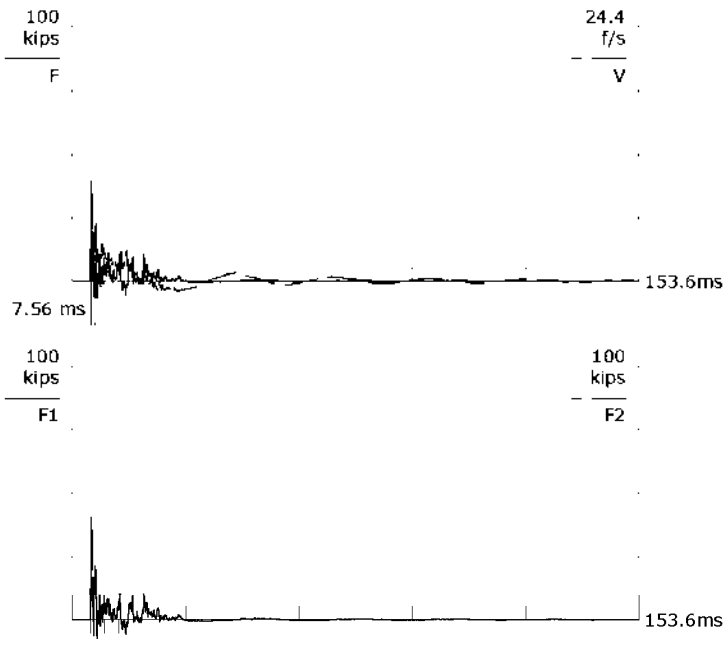
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 23/24
21/03/2015 11:57:40 AM

CSI	17.6 ksi
CSX	17.2 ksi
EMX	0.2 k-ft
RMX	kips
ETR	43.5 (%)
BTA	0.0 (%)
FMX	40 kips
DMX	0.33 in
DFN	0.32 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

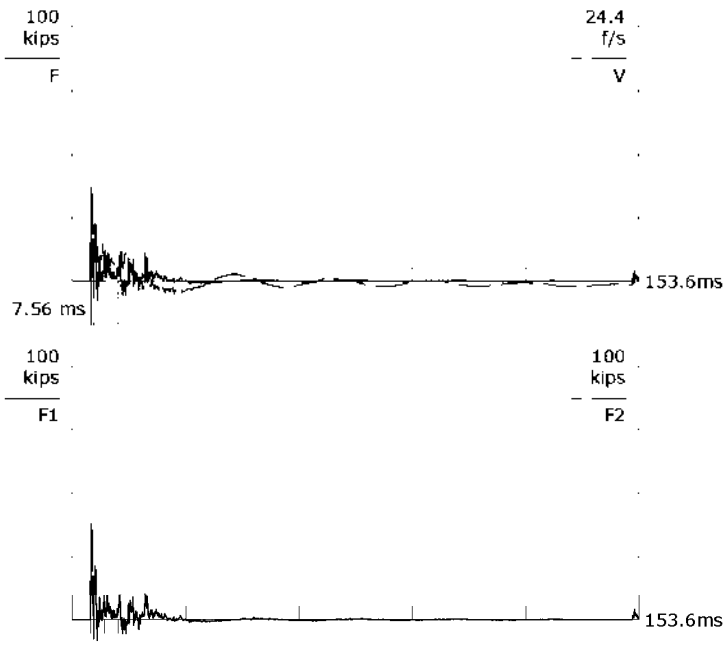
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 24/25
21/03/2015 11:57:44 AM

CSI	16.6 ksi
CSX	16.2 ksi
EMX	0.1 k-ft
RMX	kips
ETR	41.5 (%)
BTA	0.0 (%)
FMX	37 kips
DMX	0.32 in
DFN	-0.08 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

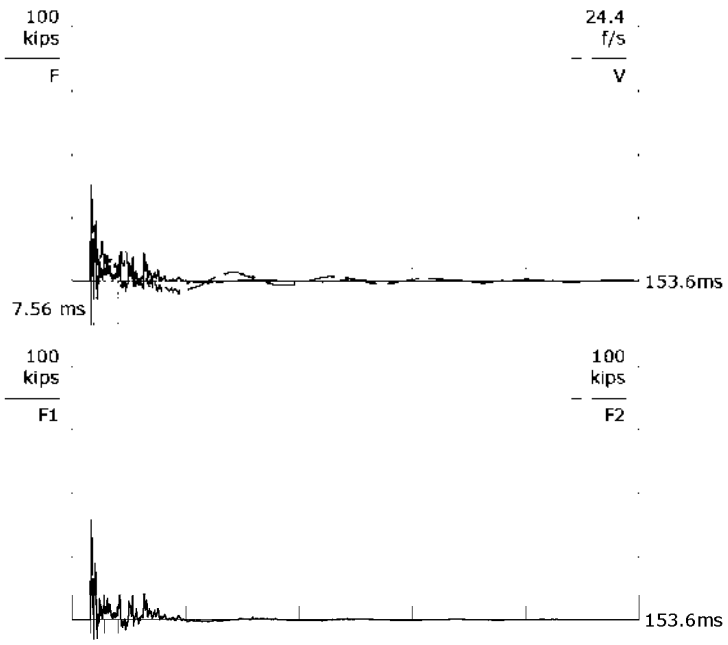
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 25/26
21/03/2015 11:57:47 AM

CSI	17.2 ksi
CSX	16.5 ksi
EMX	0.1 k-ft
RMX	kips
ETR	39.9 (%)
BTA	0.0 (%)
FMX	38 kips
DMX	0.31 in
DFN	0.29 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

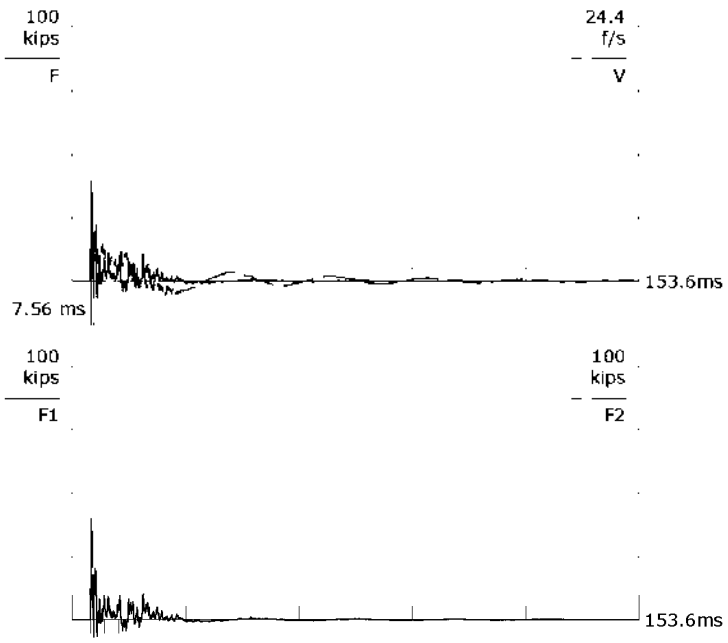
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 26/27
21/03/2015 11:57:50 AM

CSI	17.4 ksi
CSX	17.1 ksi
EMX	0.1 k-ft
RMX	kips
ETR	42.0 (%)
BTA	0.0 (%)
FMX	39 kips
DMX	0.32 in
DFN	0.30 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

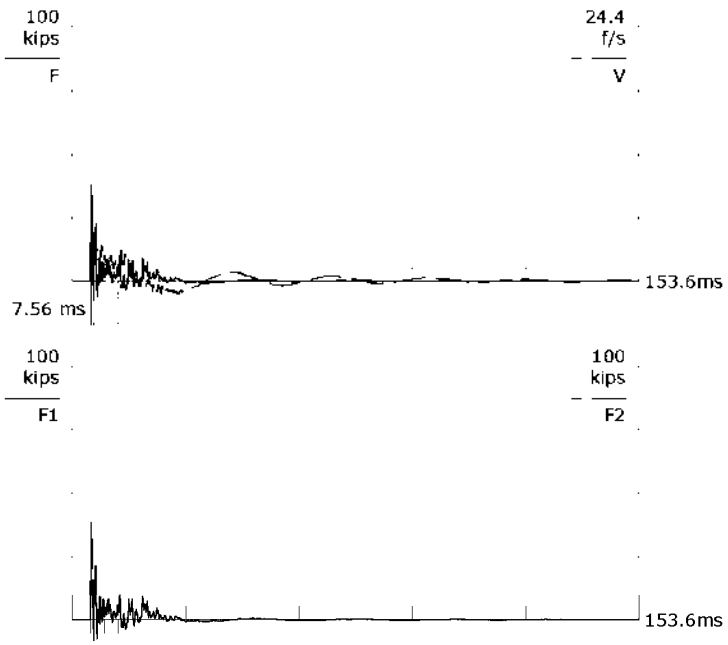
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 0/28
21/03/2015 11:57:53 AM

CSI	16.7 ksi
CSX	16.6 ksi
EMX	0.1 k-ft
RMX	kips
ETR	41.8 (%)
BTA	0.0 (%)
FMX	38 kips
DMX	0.32 in
DFN	0.32 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.50 ft

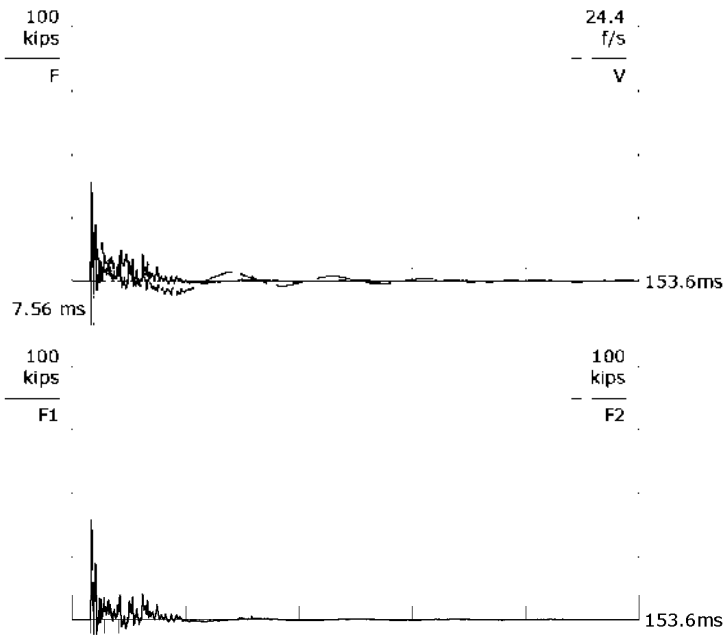
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 0/29
21/03/2015 11:57:56 AM
CSI 17.3 ksi
CSX 17.0 ksi
EMX 0.1 k-ft
RMX kips
ETR 40.5 (%)
BTA 0.0 (%)
FMX 39 kips
DMX 0.30 in
DFN 0.26 in

LE 63.00 ft
AR 2.30 in^2
EM 30000 ksi
SP 0.492 k/ft3
WS 16807.9 f/s
EA/C 4.1 ksec/ft
LP 61.00 ft

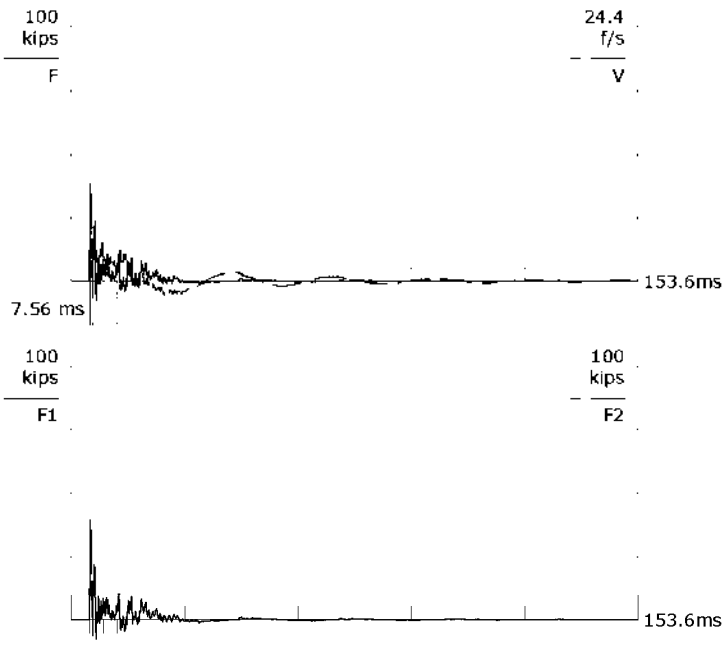
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 1/30
21/03/2015 11:57:59 AM

CSI	17.2 ksi
CSX	16.7 ksi
EMX	0.2 k-ft
RMX	kips
ETR	42.9 (%)
BTA	0.0 (%)
FMX	38 kips
DMX	0.31 in
DFN	0.24 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	61.00 ft

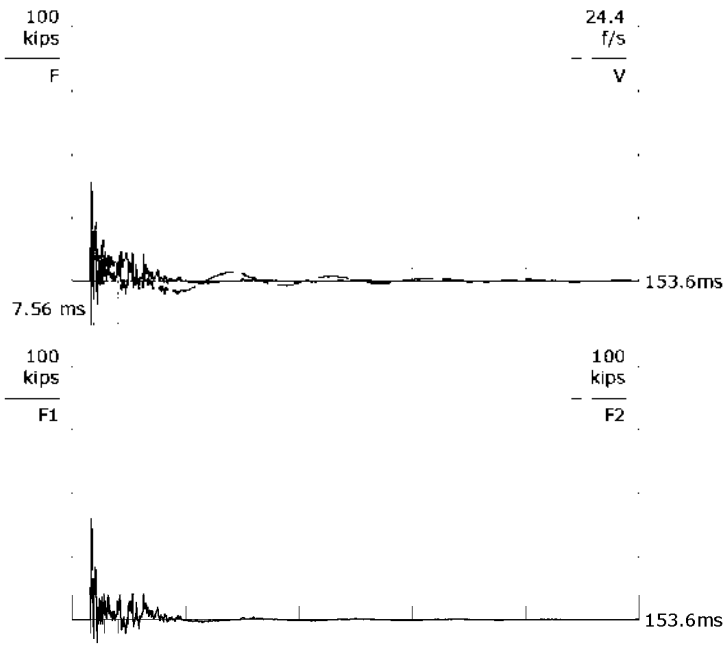
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 2/31
21/03/2015 11:58:02 AM

CSI	17.5 ksi
CSX	17.0 ksi
EMX	0.2 k-ft
RMX	kips
ETR	44.2 (%)
BTA	0.0 (%)
FMX	39 kips
DMX	0.33 in
DFN	0.32 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	61.00 ft

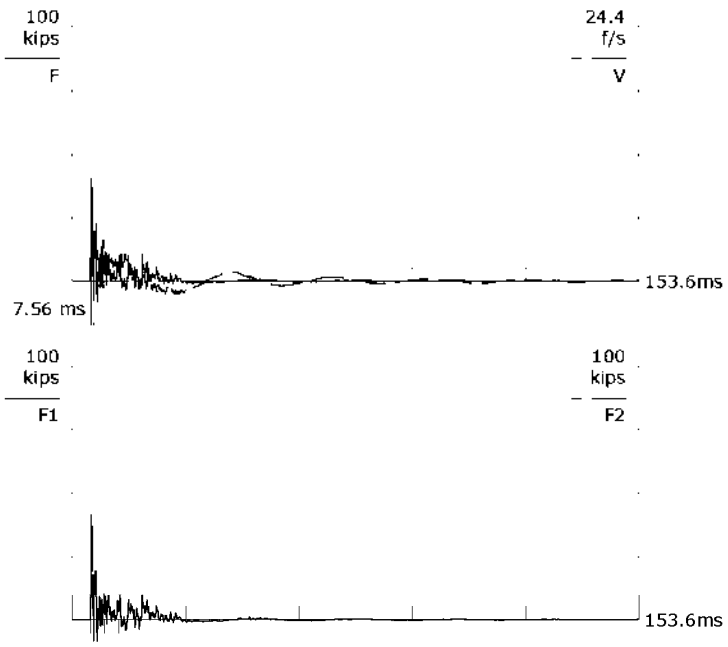
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 3/32
21/03/2015 11:58:05 AM

CSI	18.0 ksi
CSX	17.6 ksi
EMX	0.2 k-ft
RMX	kips
ETR	43.7 (%)
BTA	0.0 (%)
FMX	41 kips
DMX	0.32 in
DFN	0.26 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	61.00 ft

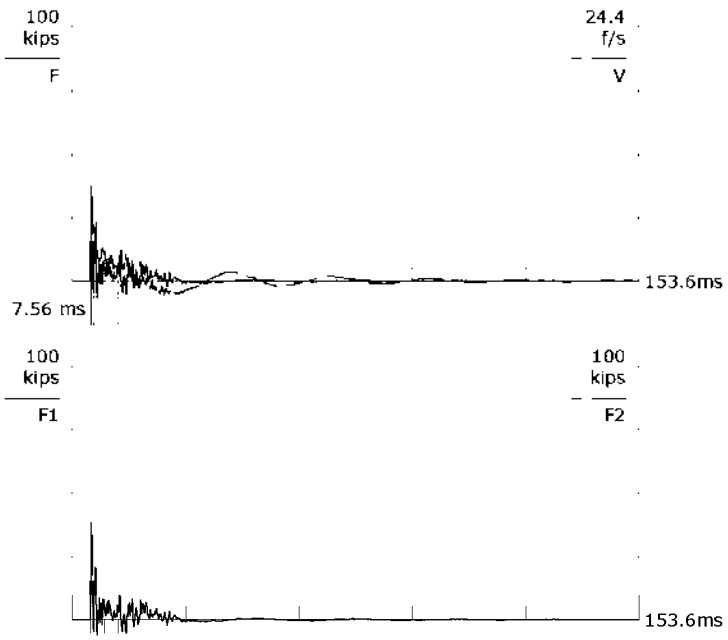
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 4/33
21/03/2015 11:58:08 AM

CSI	16.8 ksi
CSX	16.4 ksi
EMX	0.1 k-ft
RMX	kips
ETR	42.0 (%)
BTA	0.0 (%)
FMX	38 kips
DMX	0.31 in
DFN	0.26 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	61.00 ft

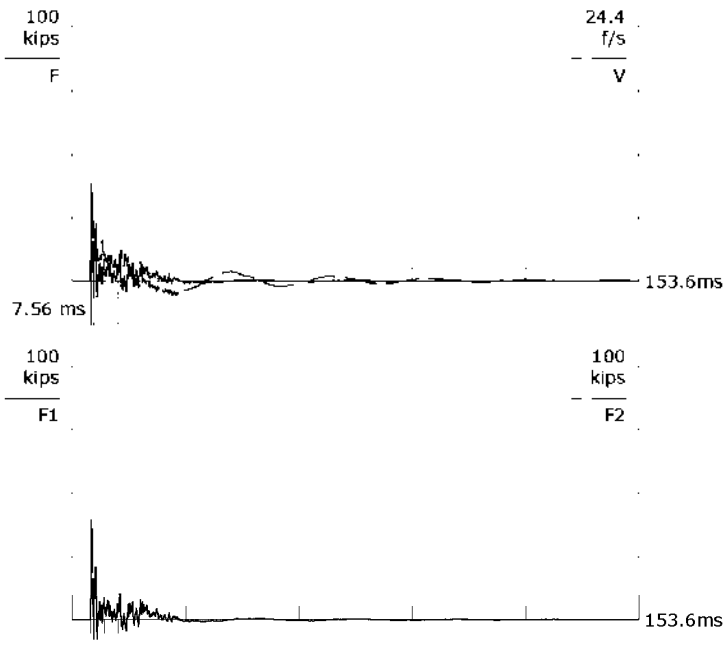
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 5/34
21/03/2015 11:58:11 AM

CSI	17.2 ksi
CSX	16.8 ksi
EMX	0.1 k-ft
RMX	kips
ETR	40.5 (%)
BTA	0.0 (%)
FMX	39 kips
DMX	0.31 in
DFN	0.28 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	61.00 ft

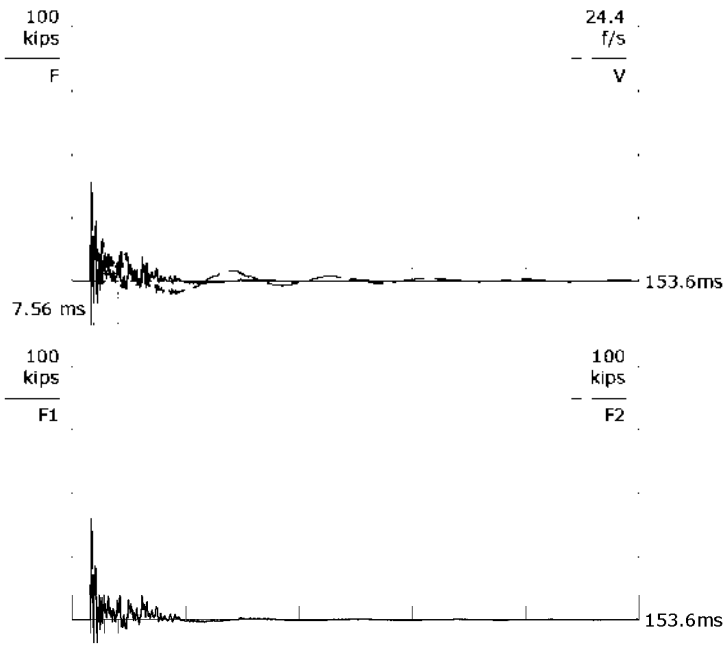
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 6/35
21/03/2015 11:58:14 AM

CSI	17.5 ksi
CSX	17.0 ksi
EMX	0.2 k-ft
RMX	kips
ETR	43.4 (%)
BTA	0.0 (%)
FMX	39 kips
DMX	0.33 in
DFN	0.33 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	61.00 ft

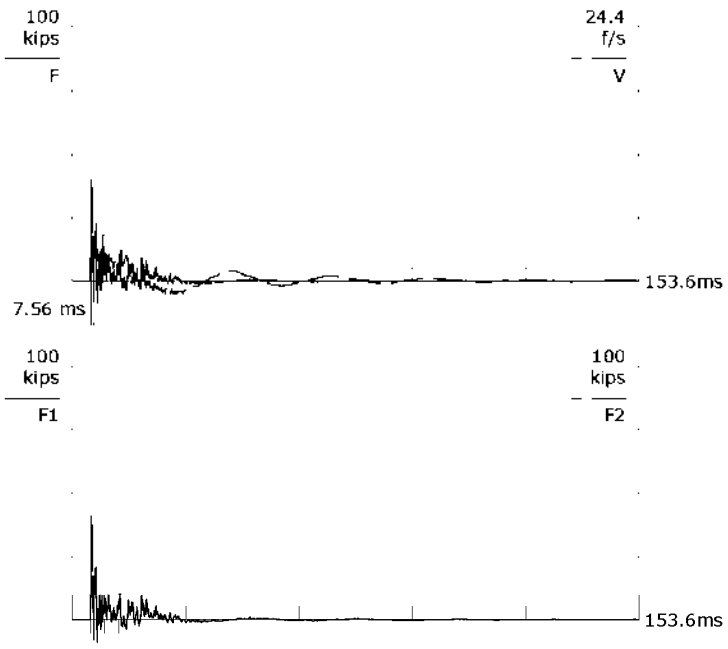
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 7/36
21/03/2015 11:58:16 AM

CSI	17.8 ksi
CSX	17.3 ksi
EMX	0.1 k-ft
RMX	kips
ETR	42.9 (%)
BTA	0.0 (%)
FMX	40 kips
DMX	0.32 in
DFN	0.32 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	61.00 ft

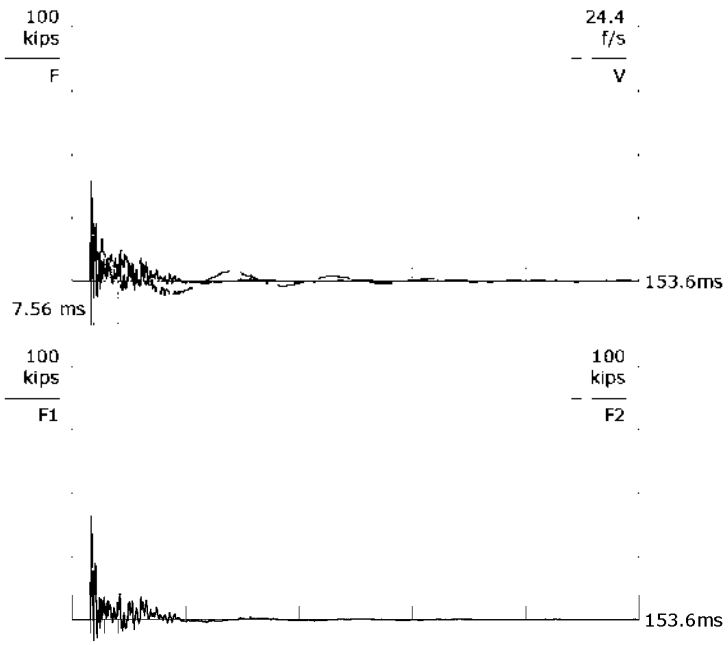
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 8/37
21/03/2015 11:58:19 AM

CSI	17.8 ksi
CSX	17.2 ksi
EMX	0.1 k-ft
RMX	kips
ETR	42.4 (%)
BTA	0.0 (%)
FMX	40 kips
DMX	0.32 in
DFN	0.30 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	61.00 ft

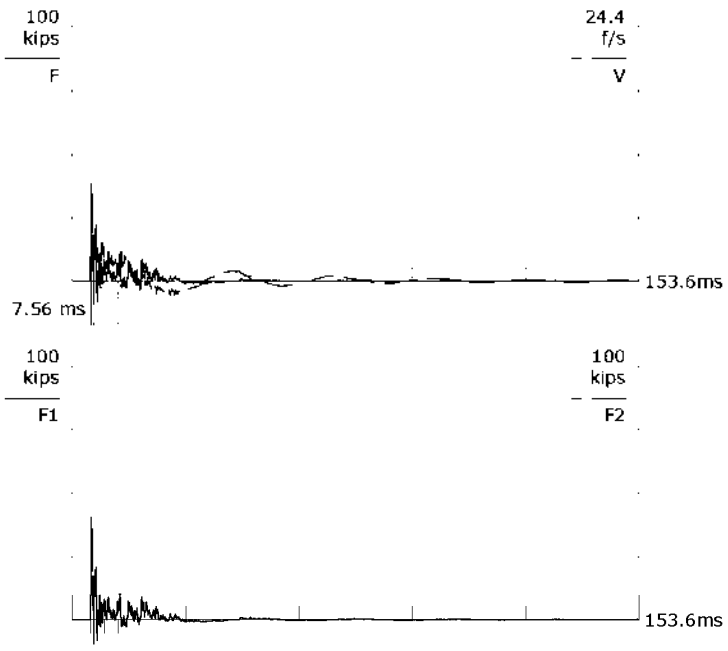
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 9/38
21/03/2015 11:58:21 AM

CSI	17.7 ksi
CSX	16.8 ksi
EMX	0.1 k-ft
RMX	kips
ETR	42.3 (%)
BTA	0.0 (%)
FMX	39 kips
DMX	0.31 in
DFN	0.28 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	61.00 ft

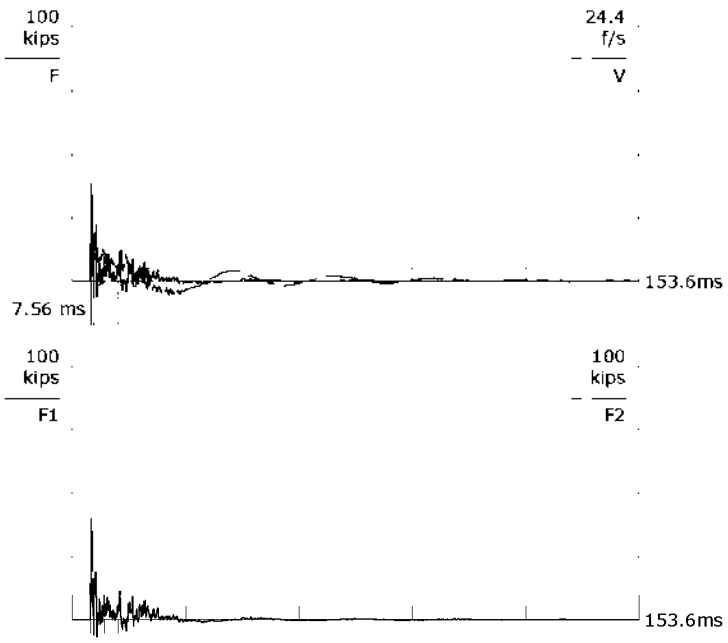
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 10/39
21/03/2015 11:58:24 AM

CSI	17.4 ksi
CSX	16.7 ksi
EMX	0.1 k-ft
RMX	kips
ETR	42.6 (%)
BTA	0.0 (%)
FMX	38 kips
DMX	0.33 in
DFN	0.33 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	61.00 ft

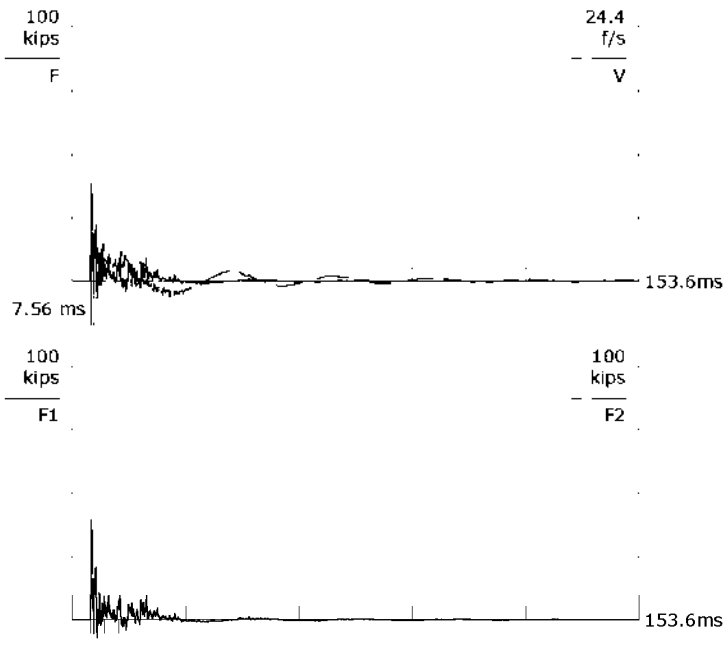
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 11/40
21/03/2015 11:58:27 AM

CSI	17.3 ksi
CSX	16.9 ksi
EMX	0.1 k-ft
RMX	kips
ETR	41.8 (%)
BTA	0.0 (%)
FMX	39 kips
DMX	0.30 in
DFN	0.29 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	61.00 ft

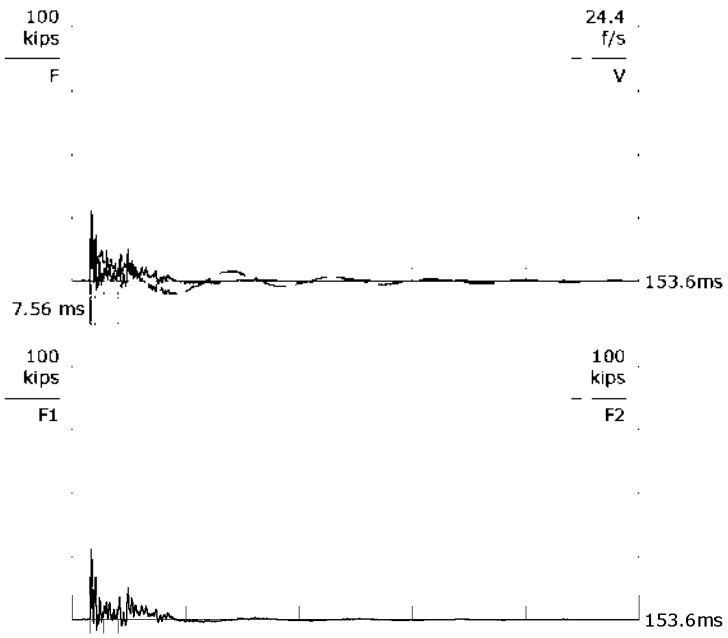
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 12/41
21/03/2015 11:58:29 AM

CSI	12.1 ksi
CSX	12.0 ksi
EMX	0.1 k-ft
RMX	kips
ETR	31.8 (%)
BTA	13.0 (%)
FMX	28 kips
DMX	0.27 in
DFN	0.18 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	61.00 ft

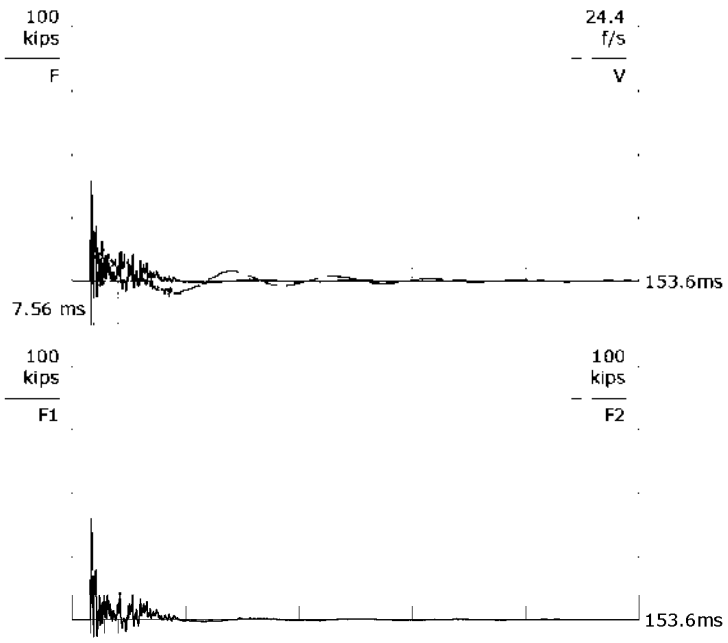
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 13/42
21/03/2015 11:58:32 AM

CSI	17.4 ksi
CSX	17.1 ksi
EMX	0.2 k-ft
RMX	kips
ETR	43.0 (%)
BTA	0.0 (%)
FMX	39 kips
DMX	0.31 in
DFN	0.28 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	61.00 ft

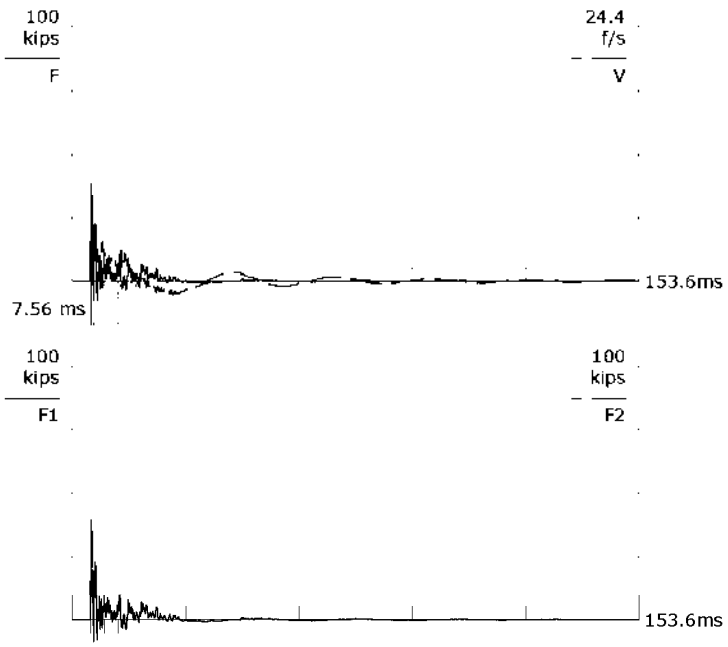
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER ®
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 14/43
21/03/2015 11:58:35 AM

CSI	17.2 ksi
CSX	16.9 ksi
EMX	0.1 k-ft
RMX	kips
ETR	41.7 (%)
BTA	0.0 (%)
FMX	39 kips
DMX	0.30 in
DFN	0.23 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	61.00 ft

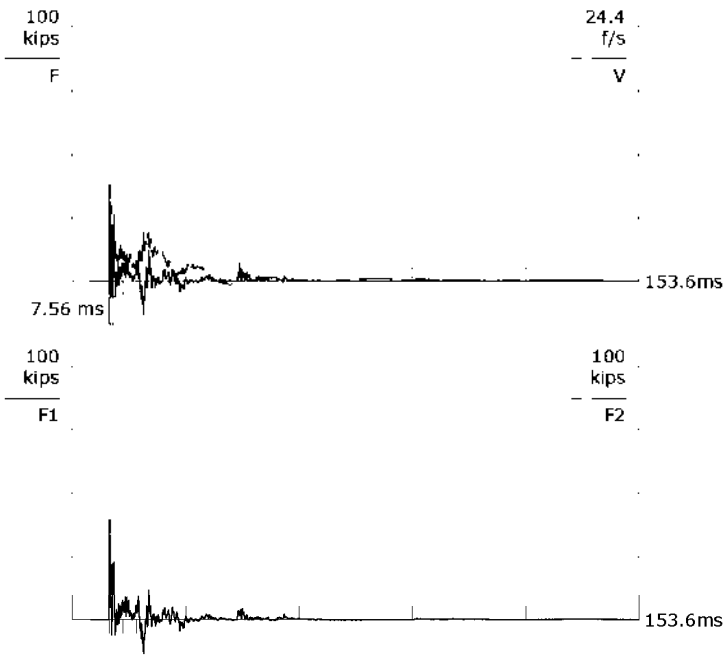
F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

Icon Engineering Services

RAJARBAG 1
PDA OP: MARUF

PILE DRIVING ANALYZER
Version 2010.101.005
BH#02_-55FT
N600SFT RAJARBAG POLICELINE



BN 1/2
21/03/2015 11:56:31 AM

CSI	17.2 ksi
CSX	16.6 ksi
EMX	0.1 k-ft
RMX	kips
ETR	42.8 (%)
BTA	0.0 (%)
FMX	38 kips
DMX	0.81 in
DFN	0.81 in
LE	63.00 ft
AR	2.30 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.9 f/s
EA/C	4.1 ksec/ft
LP	60.00 ft

F34 A34

F3: [BRIDGE1] 215.87 (1)
F4: [BRIDGE2] 215.7 (1)
A3: [K4609] 400 mv/5000g's (1)
A4: [K4610] 384 mv/5000g's (1)

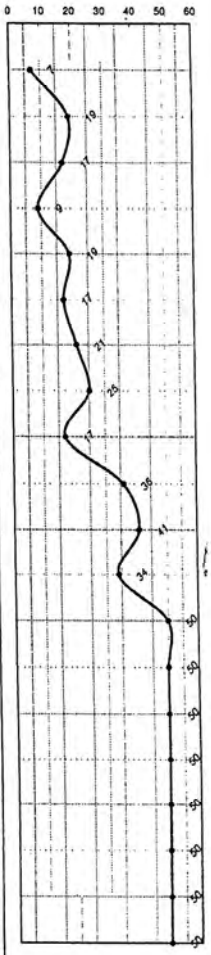
Appendix-C

BORE LOG

Project:	Proposed 600 sft Twenty (20) Storied Residential Building		
Client:	Executive Engineer	Existing Ground Level (RL in m):	+ 29.52
Borehole No:	02 (Sheet 1 of 1)	Date Started:	20-Mar-15
Method of Boring:	Percussion Method / Auto Trip Hammer	Date Completed:	22-Mar-15
Depth of Boring (m): 30.0	Boring Dia (mm): 100	Datum: Top of Floor PL RL: + 30.0 m	
Soil Classification:	ASTM D-2487 & D-2488	ICON ENGINEERING SERVICES	
Location :	Rajarbag Police Line, Dhaka, Bangladesh	49/1/A, Purana Paltan Line, Paltan, Dhaka	

Depth Below EGL (m)	Sample ID	Sample Type	RL (m)	Thickness (m)	Description of Soil Strata	Symbols	SPT Interval	Fines (%)	Liquid Limit (LL)	Plasticity Index (PI)	q_u (ksf)	N.M.C (%)	SPT N-Value
1.5	D-1		28.02	6.75	Gray spotted brown, medium to very stiff, medium plasticity, ***Lean CLAY, CL***		1.5	98	45	29		19.4	7
2.5	UD-1		27.02									30.6	
3.0	D-2		26.52				3.0					14.6	19
4.5	D-3		25.02				4.5						17
6.0	D-4		23.52										9
7.5	D-5		22.02	12	Brown, medium dense to dense, nonplastic, ***SILT, ML***, trace of mica		7.5						19
9.0	D-6		20.52				9.0						17
10.5	D-7		19.02				10.5						21
12.0	D-8		17.52				12.0						25
13.5	D-9		16.02				13.5	98					17
15.0	D-10		14.52				15.0						36
16.5	D-11		13.02				16.5						41
18.0	D-12		11.52				18.0						34
19.5	D-13		10.02	11.25	Brown, dense, ***Silty SAND, SM***, trace of mica		19.5	43					50
21.0	D-14		8.52				21.0						50
22.5	D-15		7.02				22.5						50
24.0	D-16		5.52				24.0						50
25.5	D-17		4.02				25.5						50
27.0	D-18		2.52				27.0						50
28.5	D-19		1.02				28.5						50
30.0	D-20		(0.48)		End of BH RL (m) (0.48)		30.0						50

Graphical Representation of field SPT N-Value



Legend:

- Split Spoon Sample
- Shelby Tube Sample
- Cohesive Soil
- Non-cohesive Soil

২৯/৪/১৫

ICON ENGINEERING SERVICES

২৯.০৪.১৫
মোহাঃ ভজির
নির্বাহী প্রকৌশলী
ঢাকা গণপূর্ত বিভাগ-১,

TECHNOSOIL INTERNATIONAL

Client	:	Executive Engineer, PWD Division-3, Dhaka.	Borehole No.	: 6 (Six)
Project	:	2 Nos. Dormitory Building	Boring Depth	: 55'-0"
Location	:	Tejgaon, Dhaka.	G.W.T.	: 15'-0" down
			Date	:

Depth Below EGL (ft)	Sample ID	Sample Type	Thickness (ft)	Description of materials	Bore Log	SPT Interval	SPT N-Value	S.P.T
5.0	D-1					5.0	10	
10.0	D-2		(22.00)	Reddish Brown medium plastic stiff to very stiff silty CLAY.		10.0	16	
15.0	D-3					15.0	22	
20.0	D-4		22.00			20.0	25	
25.0	D-5					25.0	24	
30.0	D-6					30.0	16	
35.0	D-7					35.0	18	
40.0	D-8		(34.00)	Brown medium dense fine SAND, some/little siltm trace mica.		40.0	16	
45.0	D-9					45.0	18	
50.0	D-10					50.0	20	
55.0	D-11		56.00			55.0	16	

