Maryland Department of Transportation
State Highway Administration

Parris N. Glendening
Governor

John D. Porcari
Secretary

Parker F. Williams
Administrator

RESEARCH REPORT

STANDARD PENETRATION TEST (SPT) CORRECTION

BY
M. SHERIF AGGOUR AND W. ROSE RADDING
THE BRIDGE ENGINEERING SOFTWARE AND TECHNOLOGY (BEST) CENTER
DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
UNIVERSITY OF MARYLAND
COLLEGE PARK, MD 20742

SP007B48
FINAL REPORT

SEPTEMBER 2001

STANDARD PENETRATION TEST (SPT) CORRECTION

Report Submitted

to

Maryland State Highway Administration
Office of Policy and Research
Contract No: SP007B48

by

M. Sherif Aggour
and
W. Rose Radding

Civil and Environmental Engineering Department
University of Maryland
College Park, Maryland
20742

September 2001

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
MD02-007B48		

4. Title and Subtitle

STANDARD PENETRATION TEST (SPT) CORRECTION

5. Report Date
September 30, 2001

6. Performing Organization Code

7. Author/s
M.Sherif Aggour and W. Rose Radding

8. Performing Organization Report No.

9. Performing Organization Name and Address

University of Maryland
Department of Civil and Environmental Engineering
College Park, MD 20742-3021

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Organization Name and Address
Maryland State Highway Administration
Office of Policy & Research
707 N. Calvert Street
Baltimore, Maryland 21202

13. Type of Report and Period Covered

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The Standard Penetration Test (SPT) is currently the most popular in-situ test in obtaining subsurface information. Although great effort has been put into standardizing the SPT procedure, variability is inherent in present procedures. Research has shown that the most significant factor affecting the measured N values is the amount of energy delivered to the drill rods. In order to reduce the significant variability of the SPT N-values due to the large variation in energy delivered, it has been recommended that the N value be standardized to a specific energy level through the use of correction factors. The purpose of this research is to summarize all available correction factors and, with the guidance of a limited field-testing program, determine the most appropriate correction factor.

This report documents a field testing program in which energy delivered by three different hammer systems, one donut, one safety, and one automatic were measured. The resulting data are presented as well as conclusions regarding the determinations and use of correction factors in correcting the SPT N-value.

17. Key Words	18. Distribution Statement
Standard Penetration test (SPT), hammer type, energy measurement	No restrictions.

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. Of Pages	22. Price
Unclassified	Unclassified	87	

TABLE OF CONTENTS

SUMMARY

The Standard Penetration Test (SPT) is currently the most popular and economical means to obtain subsurface information. Although great effort has been put into standardizing the SPT procedure, 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. Thus the test is performed by different equipment and testing procedures as well as different operators. Consequently, the consistency of the SPT N values is questioned, i.e., the ability of the test to reproduce blow counts using different rig systems under the same site/soil conditions. The direct impact of this inconsistency on geotechnical design quality and cost has sparked significant research on the factors that affect the N values.

Research has shown that the most significant factor affecting the measured N values is the amount of energy delivered to the drill rods. Field testing indicated that the energy delivered to the rods during an SPT test can vary from 30 to 90% of the theoretical maximum, depending on the type of hammer system used. 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 through the use of correction factors.

The purpose of this research is to summarize all available correction factors and, with the guidance of a limited field testing program, determine the most appropriate correction factor for use by the Maryland State Highway Administration (MD SHA).

In the field testing, SPT energy transfer measurements were made using an SPT Analyzer manufactured by Pile Dynamic, Inc. for 3 SPT hammer systems, one donut, one safety, and one

automatic hammer. All tests were performed under field conditions with normal operating procedures. The tests were performed in three borings at the same location so that similar soil conditions would be encountered, and hence the effect of different soil types on the measured energy was eliminated. Unfortunately, the method of drilling was not the same in all three borings, one boring used hollow stem auger and the other two used casing and drilling fluid.

The analysis of the field data showed that both the safety hammer and the automatic hammer have an energy efficiency that lies within the range of similar hammers tested by other researchers, whereas the donut hammer showed a much higher efficiency than was expected. It was also found that the range of published correction factor values is so wide that the published values would not be acceptable for use in design. It is thus concluded that correction factors should be determined from actual energy measurements of each driller-rig-hammer system. A chart is included in the report to correct the N value determined in the field to N_{60}, as well as recommendations regarding an energy measurement program for immediate and future implementation.

ACKNOWLEDGEMENTS

The research reported herein was sponsored by the Maryland Department of Transportation, State Highway Administration. The authors are grateful for their support.

Sincere appreciation is due to Mr. Mark F. Wolcott, Chief of the Geotechnical Exploration Division, for his support and contributions during the course of the project. The authors are grateful to Mr. Danesh Sajedi for his arrangement of the field testing as well as his providing vast field experience during the testing program.

Thanks are also extended to the drillers and their helpers: Linwood Clarke, Robert Suit, Allen Arnold, George Foster, Bruce Mielke, Roy Butler and Rodney May.

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

Introduction

1.1 General Overview

The Standard Penetration Test, known as the SPT, is commonly used by Maryland SHA in its 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 tests 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 test is anything but standard.

The SPT test, 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 influencial due to the variability in energy delivered to the drill rods. Researchers have shown that energy transfer efficiency can be 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. These findings and the recognition of the direct impact of this inconsistency on geotechnical design quality and cost were the initial motivation for the body of research into the SPT energy measurements and in the development of correction factors to reduce the variability in N values.

1.2 Objective of the Study

The objective of the study is to determine the most appropriate correction factors for the SPT N values to be used by MD SHA engineers. MD SHA engineers will have the benefit of being sure that the SPT data used is representative of actual subsurface conditions, regardless of the type of equipment used in performing the test.

The study is comprised of three tasks. Task 1 is a literature review. In this task a summary of the available correction factors is provided. The second task is field testing. In this task a limited testing program to measure the energy delivered by different types of hammers for three MD SHA hammers was under taken. The field data was used for comparison with published measured data. And finally task 3 is the presentation of the analysis of the data and recommendations for how to correct the SPT N values and what are the most appropriate correction factors.

1.3 Organization of the Report

This report is divided into six chapters. Chapter II presents the review of the literature that includes previous testing as well as available correction factors. Chapter III discusses the energy measuring system used in this study. Chapter IV presents the field testing program. Chapter V discusses the analysis of the data, and finally, Chapter VI is the conclusion and recommendations developed from the research program.

CHAPTER II

Review of Literature

2.1 History of SPT

Two very thorough treatments of the history of SPT testing 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. Readers should see Davidson, Maultsby and Spoor (1999) and the Broms and Flodin (1988) reports for more information on the history.

2.2 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. 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 2.1, produced from NAVFAC DM 7.1, 1982.

2.3 Main 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.

Table 2.1 Procedures That May Effect The Measured "N" Values (from 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. (This may also prevent sample recovery.)
Not seating the sampler 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.
Overwashing ahead of casing	Low blow count may result for dense sand since sand is loosened by overwashing.
Drilling method	Drilling technique (e.g., cased holes vs. mud stabilized holes) may result in different N-values for the same soil.

Table 2.1 Continued

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.

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).

2.4 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%.

The common practice in performing the SPT is to raise the hammer 30 in. by means of a rope wrapped around a rotating pulley and then throw the rope smartly to dissociate it from the pulley, in this way letting the hammer fall onto the anvil fastened to the top of the drill stem. Since the rope is rarely completely dissociated from the pulley, the actual energy delivered using this technique depends on the skill of the operator, smoothness of cathead (amount of rust) and very much on the number of times the rope is originally wrapped around the pulley. Kovacs et al. (1982) recommended that two turns of the rope around the pulley should be used to minimize the importance of the number of turns and operators characteristics as variables of the delivered energy.

To eliminate the variability of the energy delivered to the hammer that rises using the rope and pulley technique, an automatic trip hammer has been introduced. A mechanical system raises the hammer and a tripping device releases it from a 30 inches height. It has been found that these systems also do not deliver the theoretical free-fall energy to the drilling rods, probably because of the energy losses associated with the anvil system at the top of the drill stem. In the United States, the two most common SPT hammer systems are the safety hammer with cathead and rope mechanism and the automatic trip hammer system.

2.5 Recent Energy Measurements

Recently, several projects were undertaken to measure the transferred energy in SPT testing. These were in the states of Washington, Oregon, Minnesota, Maryland and Florida.

2.5.1 State of Washington

The Seattle branch of ASCE volunteered to study the energy transfer efficiency of local drill rig hammer systems in 1995, as presented by Lamb (1997). Washington DOT supplied their drill rigs and the testing was performed by GRL & Associates with the Pile Driving Analyzer. Safety hammers, cathead and rope systems delivered 51% to 75% energy and the Central Mine Equipment (CME) automatic hammers delivered an average of 77%.

2.5.2 State of Oregon

In 1994, energy transfer measurements in SPT were conducted by GRL for drill rigs operated by the Oregon Department of Transportation. Tests were conducted at 5 sites, in 10 test holes where nine Oregon DOT rigs were tested.

The efficiency values obtained by GRL using the measured force and velocity was as follows: For test holes with rope and cathead operation the average efficiencies ranged from 61% to 65%. Results for the automatic hammers manufactured by CME yielded average efficiencies of 78% to 82%. Additionally, two Mobile automatic hammers were tested. These hammers, one a hydraulically powered trip hammer averaged 62% efficiency and the other, a spooling winch safety hammer system averaged 48% efficiency.

2.5.3 State of Minnesota

As presented by Lamb (1997) Minnesota DOT, first noticed the variability of N values produced by their state rigs on a project in which two rigs with different hammer systems were sampling in similar soil conditions. They found that the N values resulting from one rig were consistently higher than the N values measured by the other. They decided to measure the energy delivered in each rig using the Pile Driving Analyzer and a specially instrumented rod. Effort was made to conduct 8 tests for each of their 4 hammer systems and measure the energy of each rig in different soil types. The study presents a discussion of the issues to be addressed in the improvement in SPT protocol. Minnesota used N rods in their study so those results are presented here. The energy transfer for the cathead rope system ranged from 61% to 75% with an average of 67 %. The CME automatic had a range of 76% to 94% with an average energy transfer of 80%.

2.5.4 Tests in Maryland

GRL, in 1999, performed energy measurements during SPT testing for Potomac Crossing Consultants using three drilling rigs that were used one at a time to advance a single bore hole by rotary drilling. All three rigs used a safety hammer with manual lifting mechanism (cathead-rope) during SPT testing. For Rig B24, the transferred efficiencies were found to be between

62% and 78% with an overall average corresponding to 72% efficiency. For Rig B57T, the transferred efficiencies ranged between 54% and 71% with an average of 62%, and for Rig B57A, the range was 59% to 68% with an average of 63% efficiency. The difference in efficiency between all three safety hammers could be attributed to the use of different rod cross-sectional areas between the different rigs.

2.5.5 State of Florida

Davidson, Maultsby and Spoor (1999) at the University of Florida presented a study that consisted of determining the energy transfer of 58 drill rig hammer systems with the intention of identifying and assessing the effect of drill rig variables on energy transfer. The report published from this study contains a comprehensive history of the development of ASTM standards for SPT testing. The report also provides a very thorough investigation of the variables that influence the SPT N value and provides a discussion of the issues that must be addressed in upcoming improvements of SPT testing protocol. Of the 58 drill rig systems tested in Florida, 43 were consultant-owned and 15 belonged to FDOT. Because of the private ownership of the drill rigs it was not possible to disrupt production schedules and therefore it was not possible to have the borings located in one site. Florida found their average energy transfer in the safety hammers with the AWJ rods to be 68.1% with a standard deviation of 9.8. The average energy transfer for automatic hammers with the AWJ rods was 83.2% with a standard deviation of 6.8. However, the average energy transfer of the safety hammer on the Mobile drill was 43.8% with a standard deviation of 3.1. There were 3 tests conducted with the Mobile Drill and all at depths less than 24 feet.

2.5.6 Summary

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%.

2.6 Standard Energy

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

$$E_{th} = \frac{1}{2}mv^2$$
$$= \frac{1}{2}\frac{w}{g}v^2$$

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 $v = \sqrt{2gh}$

where h is the height of fall

then $E_{th} = \frac{1}{2}\frac{w}{g}2gh = wh$

thus, a 140 lb ram raised 30 inches (2.5 ft) above an impact surface will have a potential energy of

$$E_{th} = 140 \times 2.5 = 350 \text{ lb. ft.}$$

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:

i.e.,
$$ER_f = \frac{\text{actual driving energy}}{\text{free fall energy}}$$

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

$$ER_{st} = \frac{\text{actual driving energy}}{\text{free fall energy}}$$

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:

$$ER_f \cdot N_f = ER_{st} \cdot N_{st}$$

where N_f is the SPT N value obtained in the field

N_{st} is the SPT N value for the standard energy

Thus,
$$N_{st} = N_f \cdot \frac{ER_f}{ER_{st}}$$

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:

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

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)

2.7 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):

$$N_{60} = N_f \cdot n_1 \cdot n_2 \cdot n_3 \cdot n_4 \cdot n_5 \cdot n_6$$

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

$$\text{correction factor} = \frac{\text{average transfered energy ratio}}{60}$$

i.e.,

$$n_1 = \frac{ER_f}{60}$$

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 1-3/8 in. I.D. shoe and a barrel that can be fitted with liners to provide a constant I.D. of 1-3/8 in. However the barrel is often used without liners. In this case the I.D. is 1-1/2 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. The correction factors are tabulated in Table 2.2 and 2.3. In Table 2.2 the correction factors are organized by parameter. In Table 2.3 the correction factors are organized by author.

Table 2.2 Correction Factors by Parameter

Length of Drill Rod		**Robertson & Wride (1997)**	**Seed (1984) Per McGregor and Duncan (1998)**	**Bowles (1996)**	**Skempton (1986)**
Length over 30 m	(+100 ft)	Less than 1	1	1	1
'10 – 30 m	(30–100 ft)	1	1	1	1
'6 – 10 m	(20–30 ft)	0.95	1	0.95	0.95
'4 – 6 m	(13–20 ft)	0.85	1	0.85	0.85
'3 – 4 m	(10–13 ft)	0.75	1	0.75	0.75
'0 – 3 m	(0–10 ft)	–	0.75	0.75	0.75

Corrections for Blow Rate (CBF)	Decourt, 1990 per McGregor and Duncan (1998)	
	Frequency of Hammer Blows	Bdf
Less than 20	10–20 blows/minute	0.95
Greater than 20	10–20 blows/minute	1.05

Anvil	Tokimatsu (1988) Per McGregor and Duncan (1998)	Skempton (1986)
Small (4.4 lbs)	0.85	0.7 – 0.8
Large (26.5 lbs)	0.7	0.6 – 0.7
Safety 5.5 lbs	0.9	0.7 – 0.8

Bore Hole Diameter	Robertson & Wride (1997)	Bowles (1996)	Skempton (1986)
Pamameter		N4	
60 – 120 mm	1	1	1
150 mm	1.05	1.05	1.05
200 mm	1.15	1.15	1.15

Sampler	Robertson & Wride (1997)	Bowles (1996)	Skempton (1986)
No linear	1.1 – 1.3	1	1.2
With liner: loose sand	1	0.9	1
With liner: dense sand, clay	1	0.8	1

Hammer Type	Seed (1984) per McGregor and Duncan (1998)	Robertson & Wride (1997)	Bowles (1996)
			n1 * =
Automatic	1.67	0.8 – 1.5	1.14 – 1.43
Pulley Safety Hammer	1	0.7 – 1.2	1 – 1.14
Donut	0.75	0.5 – 1.0	0.64

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

Table 2.3 Correction Factors by Author

Corrections proposed by Robertson and Wide (1997)

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

Corrections proposed by Bowles (1996)

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

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

Table 2.3 Continued

Corrections proposed by Skempton (1986)

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

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

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

CHAPTER III

Energy Measuring System

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 SPT Analyzer

The SPT analyzer used in this research is manufactured by Pile Dynamics, Inc. (PDI) and was purchased by the MD DOT. The analyzer consisted of an instrumented 2-foot long AWJ 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. It was possible to monitor, with some difficulty, the results during the operation such that defective gauges could be detected.

3.1.1 Rod and Sensors

The two foot rod size AWJ is the same size as the drill string used in the State of Maryland. Foil strain gauges (350 ohm) glued directly onto the rod in a wheatstone bridge configuration measure strain, which is converted to force using the cross-sectional area and modulus of elasticity of the rod. Two piezoresistant accelerometers are housed in a rigid aluminnm 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.

3.1.2 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 force and 2 velocity. 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:

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

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 (Abou-matar 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:

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

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.

CHAPTER IV

Field Testing Program

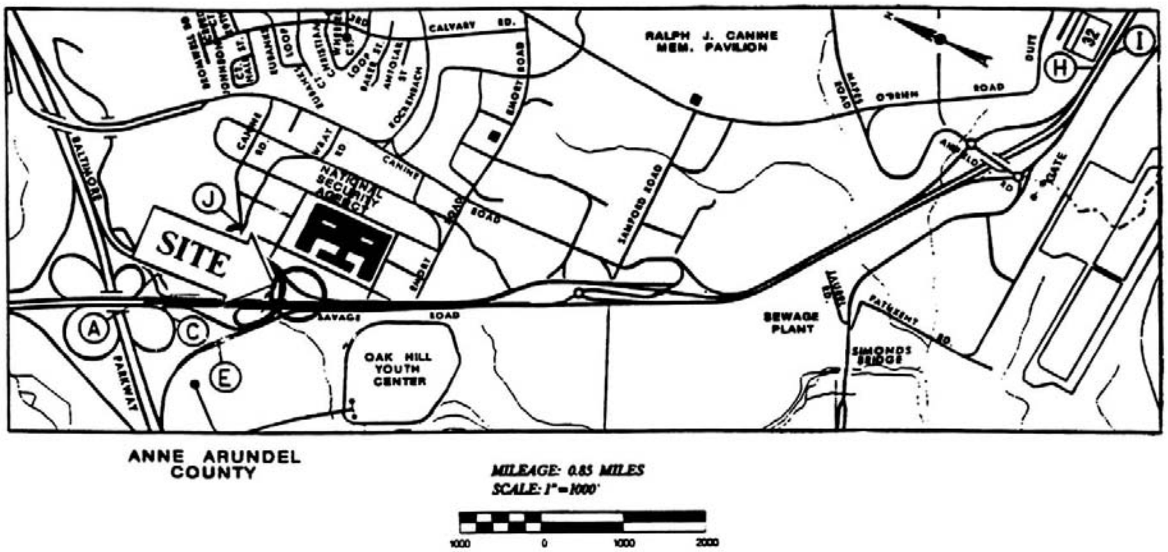
4.1 Testing Location

The testing was conducted at the intersection of Canine Road and Route 32 in Fort Meade, Maryland. The site was chosen for the convenience of the production schedule of the State Highway Administration. A total of three borings were used in this study. Three different hammers were used in performing the SPT test. The locations of the first two borings B-4 and B-4-1 were approximately 15 feet apart and the third boring B-4-2 was drilled 5 feet further Northeast from the second. Figure. 4.1 shows a site location map and Fig. 4.2 shows a site plane with the location of the borings marked. Appendix A shows the boring logs.

The borings were drilled as close as possible so that the stratigraphy encountered by the borings would not be different. This was found to be the case, as indicated by the site profile shown in Fig. 4.3.

4.2 Testing Procedure and Equipment Used

An attempt was made to drill each boring to 100 feet, however, refusal was reached at 79 feet and drilling was terminated. Samples were taken every 5 feet as is standard practice for SHA. 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 drill rigs considered for this report are a CME ATV Rig model 550 mounted with an automatic hammer from 1987, a Mobile Drill B-61 from 1987 with a safety pin hammer, and a Sprague and Henwood 140 pound donut hammer. The rope used was in good condition. No liner was used in the split spoon sampler.



STATE OF MARYLAND
DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION
HIGHWAY DESIGN DIVISION
MD 32
CANINE ROAD INTERCHANGE
FROM EAST OF MD 295 TO EAST OF EMORY ROAD

CONT. NO. AA665170 F.A.P. NO. SEE TITLE SHEET SHEET NO. 17 OF 178
PREL. TRAC. BY ______ FINAL TRAC. BY ______

Fig. 4.1 Site Location

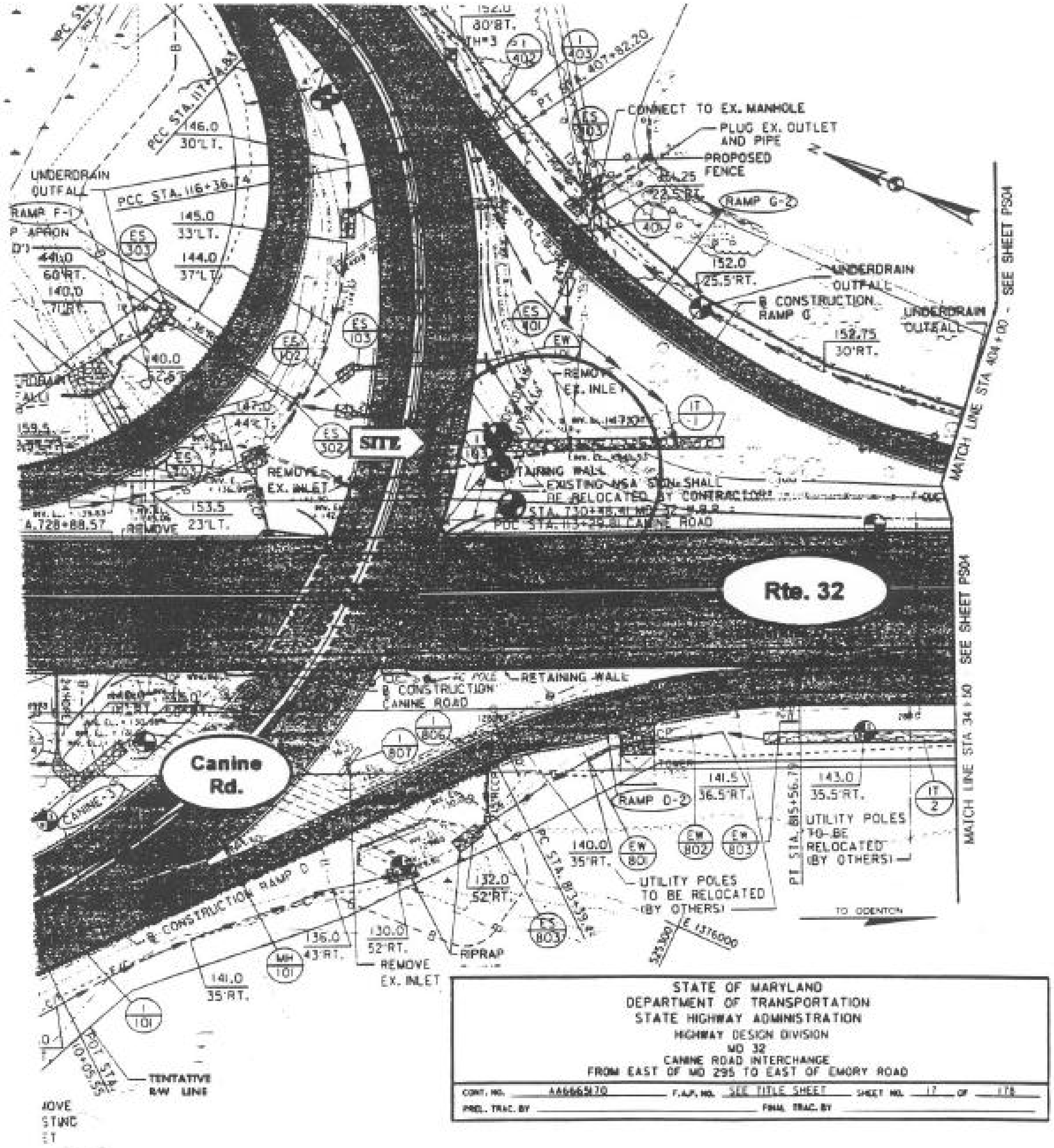


Fig. 4.2 Site Plane

Depth, ft	Automatic B-4 N	Safety B-4-1 N	Donut B-4-2 N	
	21	25		
10	12	15	23	
	16	19	23	SAND with trace of gravel
20	▼ 14	16 ▼	12	
	14	25	17	
30	22	40	60	
	42	57	59	clayey SILT
	18	20	35-50/3"	
40				
	60			
50	84	25-50/5"		SAND with trace of silt
	51			
60	27-50/6"	34-50/3"		
	25-50/4"	65		
	50/5"			SILT
70	50/3"	50/2"		SAND with trace of gravel

Fig. 4.3 Site Profile

The drill stems were comprised of AWJ-type rods. All drilling equipment was the property of the Maryland State Highway Administration.

The safety hammer uses a rotating cathead around which the operator wraps a rope 1¾ times around for a counter clockwise rotating cathead and 2¾ times for a clockwise rotating hammer and pulls to raise the hammer 30 inches. The operator then smartly disassociates the rope from the pulley to enable the hammer to fall with minimal friction. The hammer rides a shaft enclosed within a housing so that there is no risk of the hammer falling off the mount, hence the name safety hammer.

The automatic hammer is a trip hammer, sometimes called a monkey trip. The release mechanism is a tripping mechanism that eliminates the operator technique as a parameter. The anvil on this drill rig is small.

Table 4.2 summarizes the information regarding the type of drill rigs and hammers used in the field testing program.

Table 4.2 Drill Rigs and Hammers Tested

Boring Number	Driller	Rig Type	Hammer Type	Year	Drilling Method	Condition of Rope	Drill Stem
B-4	Al	CME ATV 550	Automatic	1987	Hollow Stem Auger		AWJ
B-4-1	Linwood	Mobile B61	Safety Pin	1987	Casing & Drilling Fluid	New	AWJ
B-4-2	Linwood	Mobile B61	Sprague and Henwood Donut	1987	Casing & Drilling Fluid	New	AWJ

CHAPTER V

Data Analysis

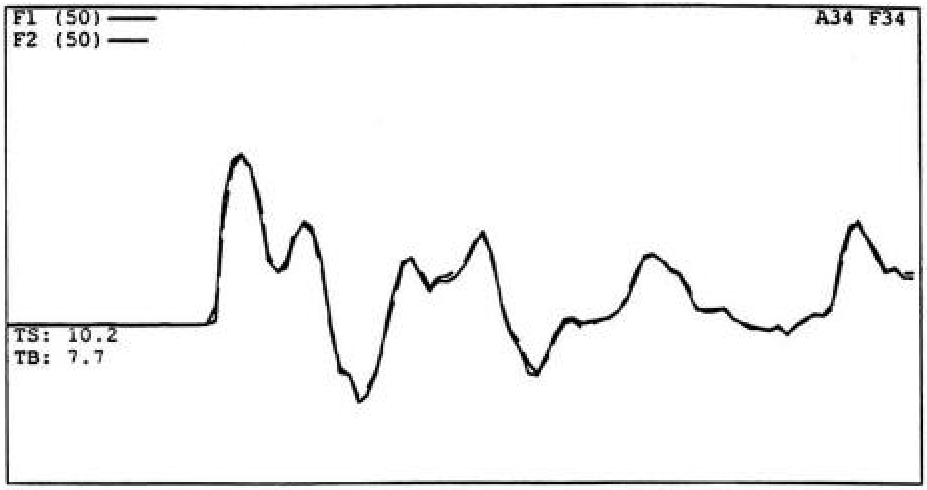
5.1 Data Quality Assessment

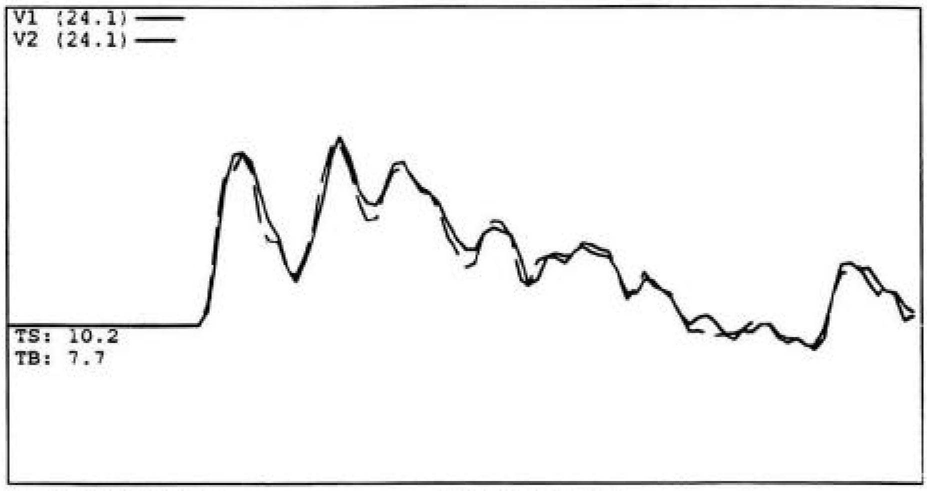
Data were downloaded onto a laptop computer and were evaluated for quality and adjusted or excluded as appropriate. Data were reviewed using the PDI program. Each blow from each SPT sample was reviewed and evaluated. The data were evaluated to ensure that all gauges were recording in phase and that all 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 effect the quality. One such event is circuit overloading. Loose bolts attaching the accelerometers to the instrumented rod is another. In our experience, accelerometer 1 frequently provided unusable data that had to be excluded. We relied on just accelerometer 2 for half of the results. Included here are sample plots of blows to illustrate the use of the plots in data quality assessment. The completed test data are presented in APPENDIX B, that includes the time, blow number, EF2, maximum force in the drill rod, maximum velocity of the rod, maximum displacement of the rod, etc.

As an example of good data, Fig 5.1 presents a typical hammer blow as presented by the PDI program. The figure shows a single blow (blow No. 19) by the safety hammer at a depth of 4.5 ft. As shown in the figure, both forces and both velocities overlap thus all gauges were working right. In Fig. 5.2 for the same blow, the upper part shows both the force and velocity wave trace together. The data shows good proportionality of the force and velocity from the initial impact to the time 2L/c. Another good data is for blow No. 50 by the safety hammer at a depth of 74.5 ft. Again Figs. 5.3 and 5.4 show good correlations between the force and velocity.

Maryland State Hwy | Pile Driving Analyzer ®

MD 32 | **B-4-1**





Project Information
PROJECT: MD 32
PILE NAME: B-4-1
DESCR: COLS OF BRIDGE;SAFETY ;MOBILE B6
OPERATOR: LINWOOD
FILE: B-4-1-2.w01
3/31/2001 10:14:58 AM
Blow Number 19

Pile Properties
LE 9.00 ft
AR 1.16 in^2
EM 30000 ksi
SP 0.492 k/ft3
WS 16807.7 f/s
EA/C 2.1 ksec/ft
2L/C 1.10 ms
JC 0.00 []
LP 4.50 ft

Quantity Results
CSX 23.3 ksi
DMX 0.52 in
EMX 0.272 k-ft
ETR 77.8 (%)
EF2 0.181 k-ft
BPM 44.0 bpm
RAT 1.4 []
DFN 0.33 in
VMX 14.1 f/s

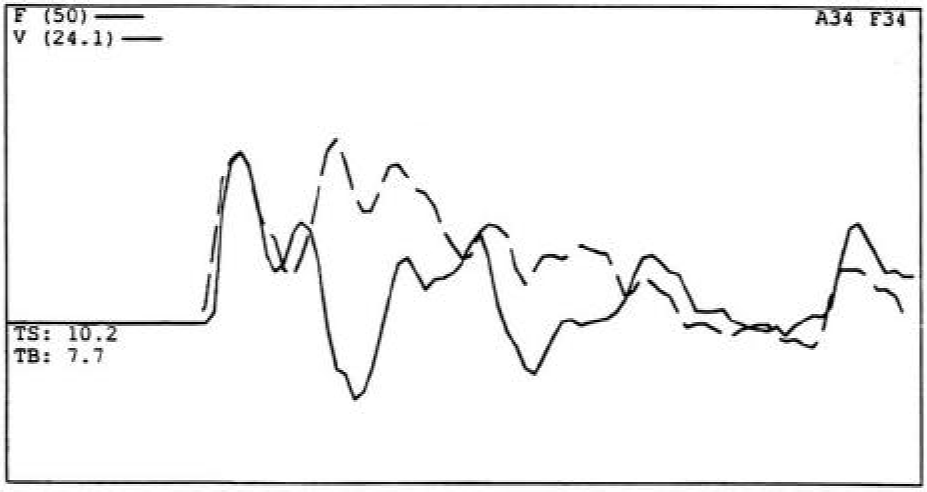
Sensors
F3: F1 219.73 (1)
F4: F2 218.87 (1)
A3: A1 395 mv/5000g's (1)
A4: A2 415 mv/5000g's (1)
CLIP: OK
F3/F4: OK 1.00
V3/V4: OK 1.00

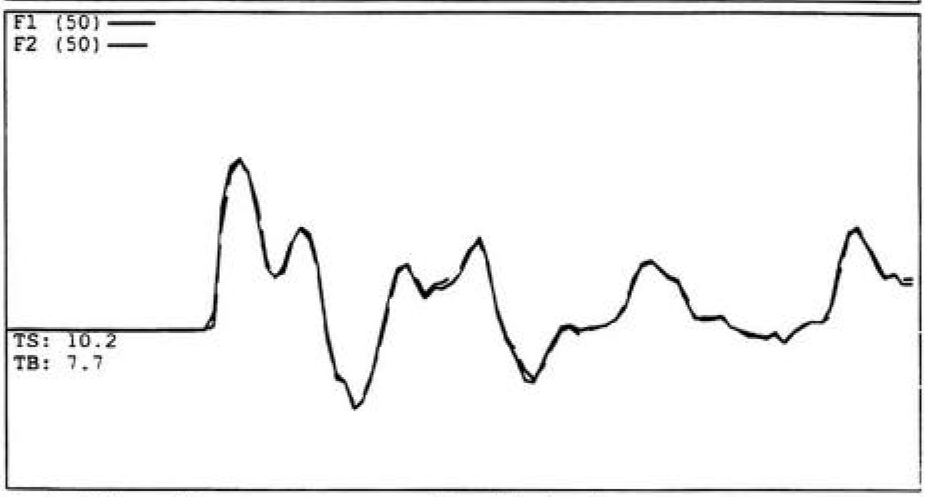
Version 2001.085

Fig. 5.1 Blow No. 19 (F1, F2 and V1, V2)

Maryland State Hwy — Pile Driving Analyzer ®

MD 32 — **B-4-1**





Project Information
PROJECT: MD 32
PILE NAME: B-4-1
DESCR: COLS OF BRIDGE;SAFETY ;MOBILE B6
OPERATOR: LINWOOD
FILE: B-4-1-2.w01
3/31/2001 10:14:58 AM
Blow Number 19

Pile Properties
LE 9.00 ft
AR 1.16 in^2
EM 30000 ksi
SP 0.492 k/ft3
WS 16807.7 f/s
EA/C 2.1 ksec/ft
2L/C 1.10 ms
JC 0.00 []
LP 4.50 ft

Quantity Results
CSX 23.3 ksi
DMX 0.52 in
EMX 0.272 k-ft
ETR 77.8 (%)
EF2 0.181 k-ft
BPM 44.0 bpm
RAT 1.4 []
DFN 0.33 in
VMX 14.1 f/s

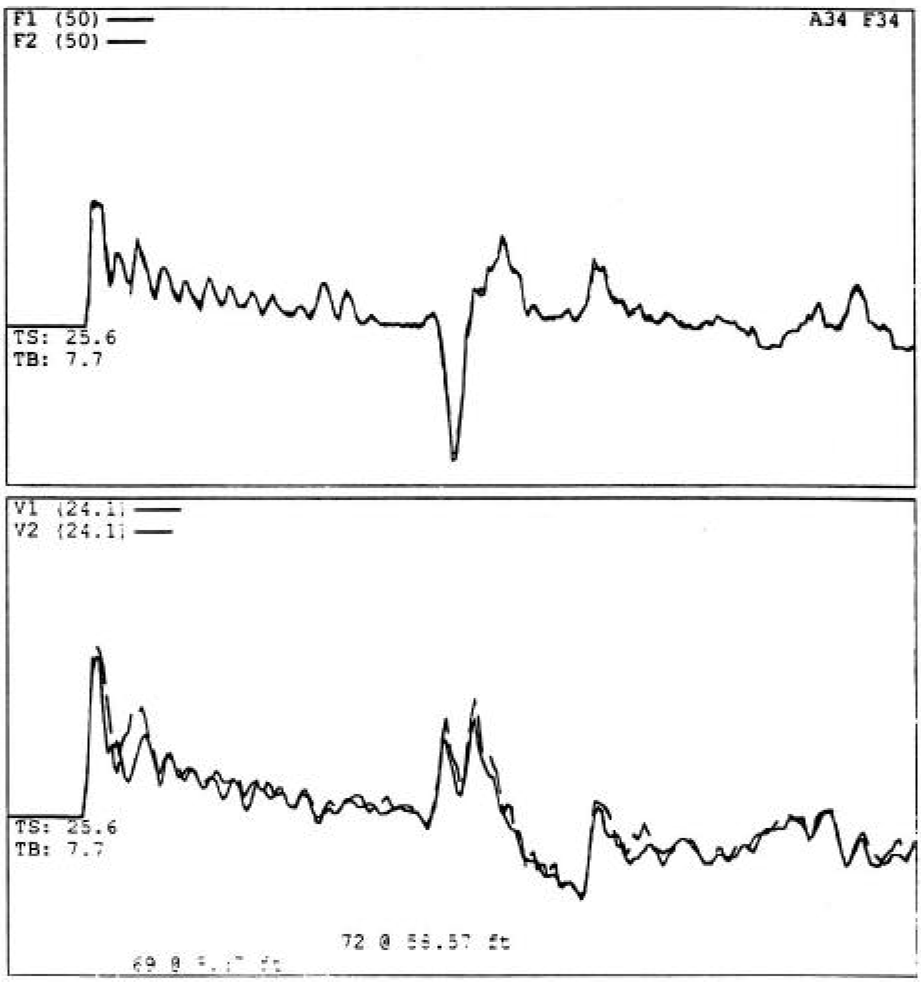
Sensors
F3: F1 219.73 (1)
F4: F2 218.87 (1)
A3: A1 395 mv/5000g's (1)
A4: A2 415 mv/5000g's (1)
CLIP: OK
F3/F4: OK 1.00
V3/V4: OK 1.00

Version 2001.085

Fig. 5.2 Blow No. 19 (Force and Velocity)

Maryland State Hwy | Pile Driving Analyzer ®

MD 32 | B-4-1



Project Information
PROJECT: MD 32
PILE NAME: B-4-1
DESCR: COLS OF BRIDGE;SAFETY ;MOBILE B6
OPERATOR: LINWOOD
FILE: B-4-1-2.w01
4/1/2001 8:57:38 AM
Blow Number 50/232

Pile Properties
LE 82.00 ft
AR 1.16 in^2
EM 30000 ksi
SP 0.492 k/ft3
WS 16807.7 f/s
EA/C 2.1 ksec/ft
2L/C 9.80 ms
JC 0.00 []
LP 74.50 ft

Quantity Results
CSX 16.8 ksi
DMX 0.42 in
EMX 0.232 k-ft
ETR 66.1 (%)
EF2 0.204 k-ft
BPM 46.1 bpm
RAT 0.9 []
DFN 0.03 in
VMX 12.6 f/s

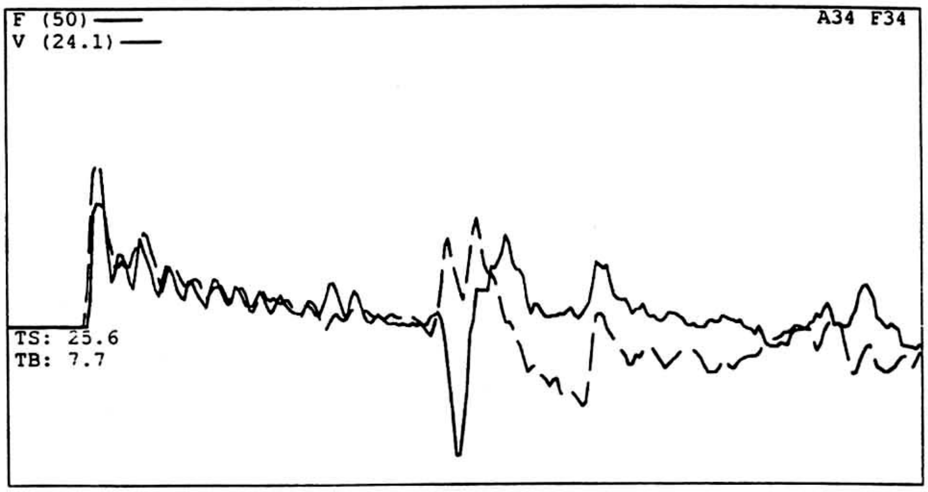
Sensors
F3: F1 219.73 (1)
F4: F2 218.87 (1)
A3: A1 395 mv/5000g's (1)
A4: A2 415 mv/5000g's (1)
CLIP: OK
F3/F4: OK 1.05
V3/V4: OK 0.94

Version 2001.085

Fig. 5.3 Blow No. 50 (F1, F2 and V1, V2)

Maryland State Hwy **Pile Driving Analyzer ®**

MD 32 **B-4-1**



Project Information
PROJECT: MD 32
PILE NAME: B-4-1
DESCR: COLS OF BRIDGE;SAFETY ;MOBILE B6
OPERATOR: LINWOOD
FILE: B-4-1-2.w01
4/1/2001 8:57:38 AM
Blow Number 50/232

Pile Properties

LE	82.00 ft
AR	1.16 in^2
EM	30000 ksi
SP	0.492 k/ft3
WS	16807.7 f/s
EA/C	2.1 ksec/ft
2L/C	9.80 ms
JC	0.00 []
LP	74.50 ft

Quantity Results

CSX	16.8 ksi
DMX	0.42 in
EMX	0.232 k-ft
ETR	66.1 (%)
EF2	0.204 k-ft
BPM	46.1 bpm
RAT	0.9 []
DFN	0.03 in
VMX	12.6 f/s

Sensors
F3: F1 219.73 (1)
F4: F2 218.87 (1)
A3: A1 395 mv/5000g's (1)
A4: A2 415 mv/5000g's (1)
CLIP: OK
F3/F4: OK 1.05
V3/V4: OK 0.94

Version 2001.085

Fig. 5.4 Blow No. 50 (Force and Velocity)

Figure 5.5 shows blow number 21 that was delivered by the automatic hammer at a depth of 40 ft below ground surface. It can be seen from the plot that the velocity in gauge 1 does not correlate to the velocity in gauge 2. However, the velocity in gauge 2 correlates with the force, thus the velocity in gauge 1 is not used and the velocity in gauge 2 is used. This case occurred when one of the two mounted accelerometer gauges malfunctioning.

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 matching the standardized N values obtained by the three hammers to check for convergence. To calculate the energy transfer ratio, the transferred energy is divided by the potential energy of the hammer before its fall.

The energy transfer ratio is then plotted versus L, the rod length, which is the distance from the mid point between the two gauges to the tip of the sampler. Figures 5.6, 5.7 and 5.8 show the energy transfer ratio as a function of drill rod length for the automatic, safety and donut hammers, respectively.

The testing found that the energy transfer from the automatic hammer was the highest of all hammers. The automatic hammer was found to provide a range of transferred energy efficiencies from 77.18% to 89.36% with an average of 81.41%. The average standard deviation was 3.95. As shown in Fig. 5.6, a moderate relationship between rod length and energy transfer is apparent where energy transfer increases with increased rod length. The values obtained for

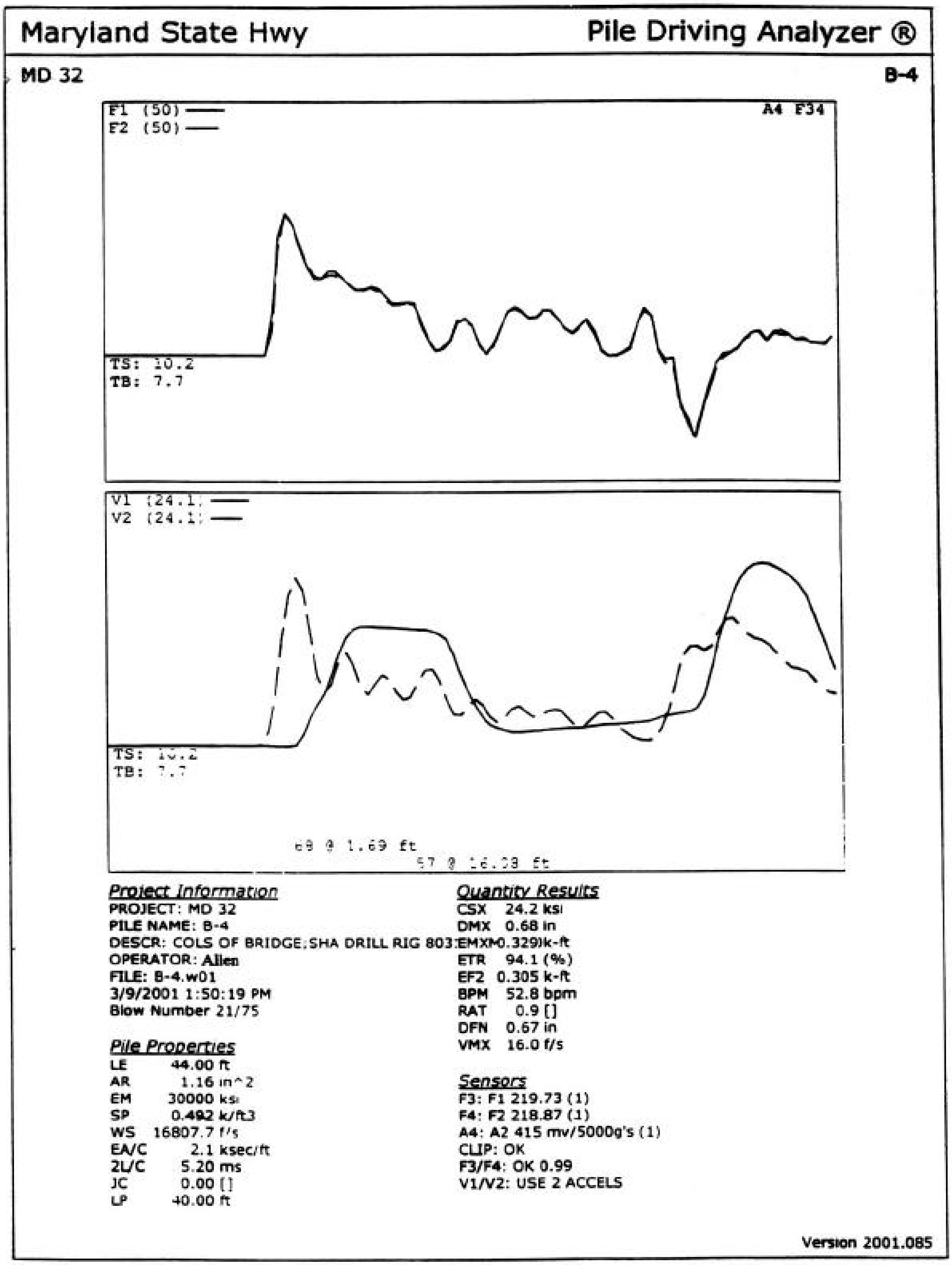


Fig. 5.5 Blow No. 21 (F1, F2 and V1, V2)

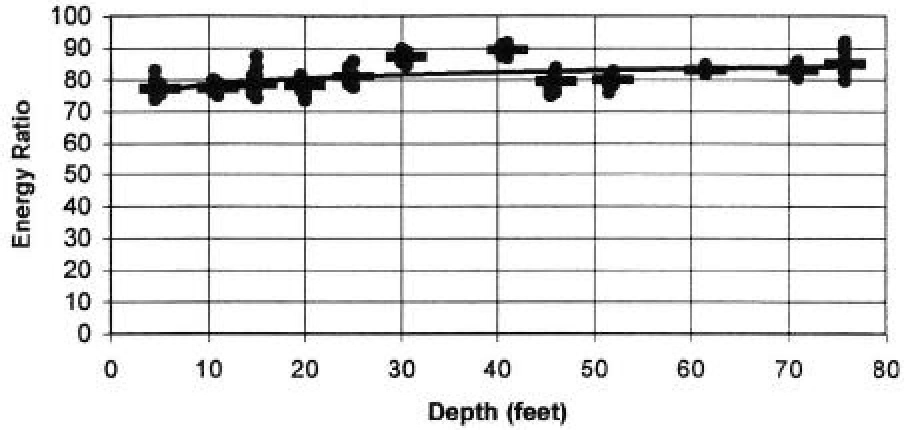


Fig. 5.6 Energy Ratio as a Function of Depth for the Automatic Hammer

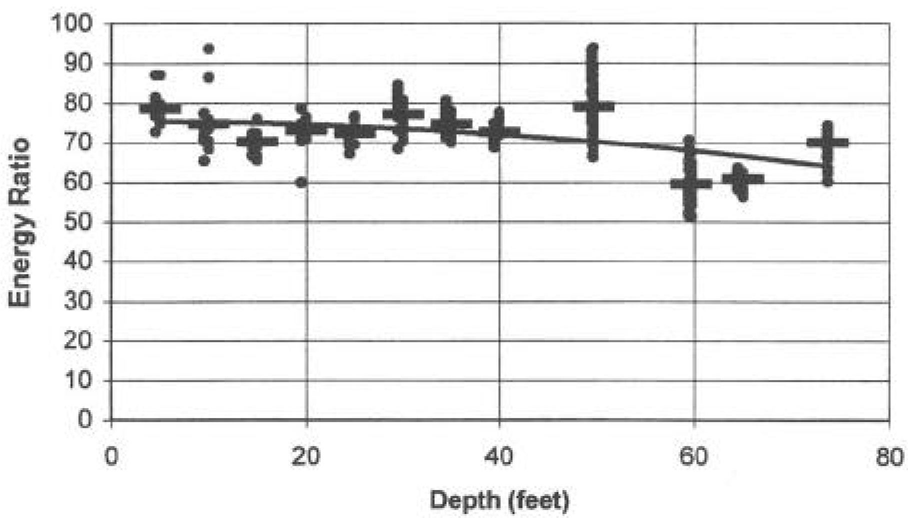


Fig. 5.7 Energy Ratio as a Function of Depth for the Safety Hammer

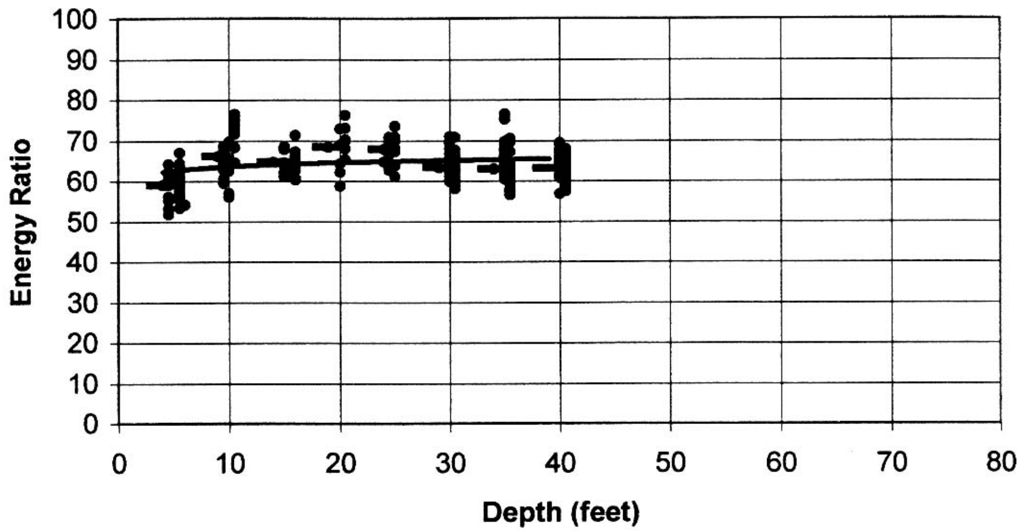


Fig. 5.8 Energy Ratio as a Function of Depth for the Donut Hammer

the efficiency fall within the range of values reported by other researchers, which would also indicate that the hammer is performing properly.

As was expected, the safety hammer was less efficient than the automatic hammer. The safety hammer was found to provide a range of transferred energy efficiency from 51.5% to 93.0% with an average of 70.2%. The average standard deviation was 8.53. Again the values obtained for the efficiency fall within the range of values reported by other researchers, which would also indicate that the hammer is performing properly.

For the donut hammer, the results were not as expected. The donut hammer was found to provide a range of transferred energy efficiencies from 51.0% to 73.6% with an average of 63.5%. The average standard deviation was 4.3. Most previous research indicated an average efficiency of 45% for the donut hammer. Thus, our donut hammer was much more efficient than was expected.

Matching the standardized N values was done by applying both field correction values as well as published correction values to the N value by each hammer and calculating the standard deviations of the three hammers at each strata. The standard deviations for the matching of N standardized for all three-hammer types were 0 to 7 for the top sandy strata. The results for the clayey silt strata were not as good. The tests below 40 feet encountered refusal. In the end, only 6 points were available for comparison, not enough for any general conclusion.

5.3 Correction Factors Based on Field Data

From the field determination of the energy transfer for each SPT system, we can now determine the correction factor. Since it has been recommended that N values be standardized to N_{60}, the correction factors will be determined from:

$$N_{60} = N_f \cdot \frac{ER_f}{60}$$

For the donut hammer, the factor will be $\frac{63.5}{60} = 1.06$, for the safety hammer will be $\frac{70.2}{60} = 1.17$, and for the automatic hammer will be $\frac{81.4}{60} = 1.36$.

CHAPTER VI

Conclusions And Recommendations

6.1 Conclusions

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 research, SPT energy measurements were made using the Pile Dynamic, Inc. manufactured SPT Analyzer for 3 SPT hammer systems, one donut, one safety, and one automatic hammer. All tests were performed under field conditions with the normal operating procedure. The tests were performed in three borings at the same location so that similar soil conditions would be encountered, and the effect of different soil types on the measured energy would be eliminated.

The following table (Table 6.1) shows the average measured transferred energy efficiencies, the appropriate correction factors based on average transferred energy efficiency of 60% for each hammer system, as well as the range of published correction factor values.

Table 6.1 Transferred Energy Efficiency and Correction Factors

Hammer System	Donut	Safety	Automatic
Average efficiency	63.5%	70.2%	81.4%
Correction factor	1.06	1.17	1.36
Range of published values	0.5 – 1.0	0.7 – 1.2	0.8 – 1.67

As mentioned before, the donut hammer showed a much higher efficiency than was expected, thus its correction factor is higher than the range of published values. Both the safety and automatic hammer correction factors fall within the range of published values.

The ASTM standard for the performance of the SPT allows for a variety of equipment to be used. There are several types of hammers in use and more types of lifting and dropping mechanisms, thus the same type of hammer could be operated differently. In addition, there are different types of drill rigs. In the literature review we found drill rigs manufactured by different manufacturers such as the Central Mine Equipment Company (CME), Diedrich, Mobile, Acker, BK and Failing. Thus the combination of hammer type and drill rig type results in a matrix of systems. These systems introduce different amounts of energy per blow into the drill rod.

This explains the wide range of published correction factors. The effect of this wide range on the N values is very pronounced. For example, the N values, using an automatic hammer could be multiplied by 0.8, i.e., reduced by 20% or multiplied by 1.67, i.e., increased by 67%, i.e., a range of 87%. Such a wide range in values is not acceptable in design. Hence, the correction factor for each drill rig should be determined from actual energy measurements.

Following the determination of the energy a figure such as Fig. 6.1 can then be used to determine N_{60} from knowledge of the blow count in the field N_f.

6.2 Recommendations

6.2.1 For Immediate Action

Most of the corrections to the SPT N value are somewhat minor, however, the corrections for the use of different hammer systems have a large impact. For this reason we recommend that:

- The State measure the transferred energy efficiency of the driller-rig-hammer system and determine a correction factor that is based on a standard energy ratio of 60% (rig calibration for both equipment and operator is highly recommended).
- Energy measurements should be done on a periodic basis that will act to verify that the rigs are functioning properly and that the effect of the wear and tear on the equipment is being considered.
- The energy measurements should also be undertaken under different environmental conditions, such as different weather conditions and at different times of day so that operator fatigue can be considered.
- Testing should be accomplished in several borings in varying soil conditions so that the effect of type of soil on energy measurements can be determined.

6.2.2 Future Action

Minnesota DOT has decided to standardize their SPT data by calibrating their hammer systems so that each would provide an average transferred energy efficiency of 60% by modifying weight or stroke. As an example, Lamb (2000) replaced the 140 lb weight with a custom-made 100 lb one to reduce the energy transfer in a new Mobile self-compensating auto

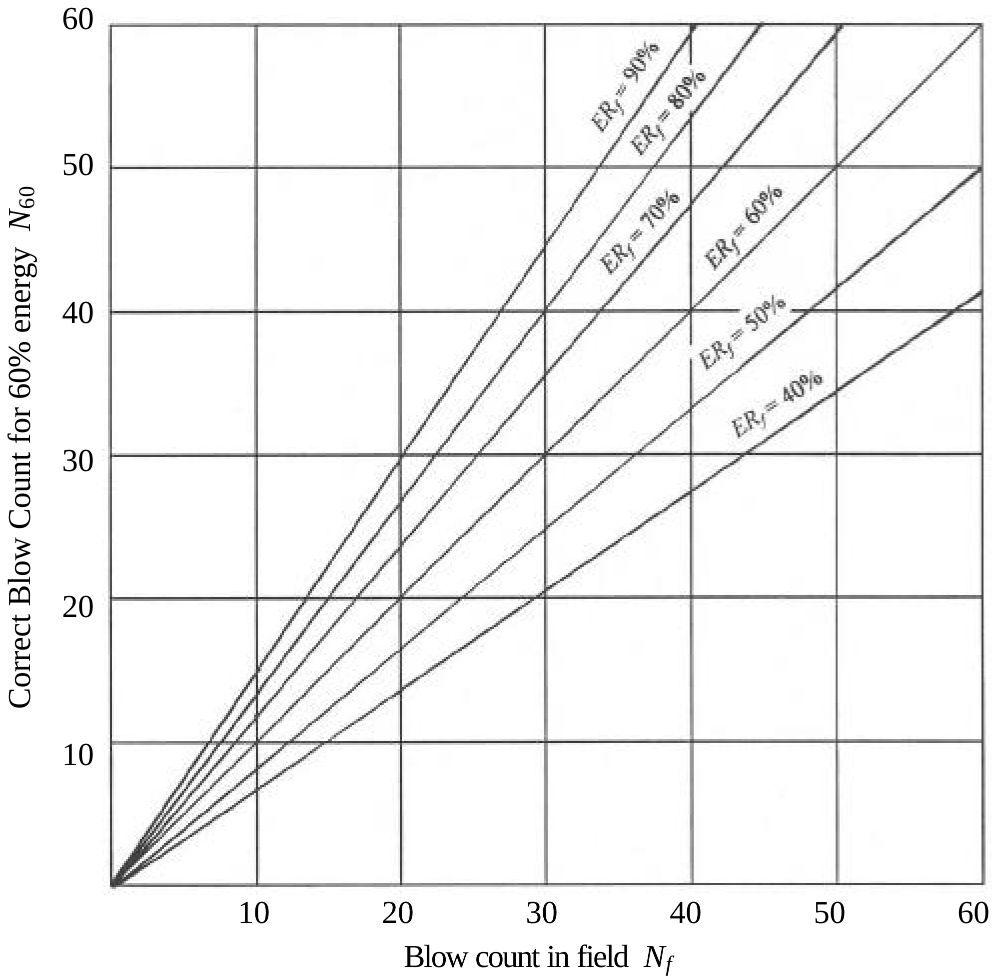


Fig. 6.1 Determination of N_{60} from N_f as a Function of Energy Transferred

hammer from 90% to a ratio of 63% to 69%. The decision to follow this direction has certain advantages and disadvantages. The table below (Table 6.2) from Lamb (1997) is reproduced and presented for MSHA discussion and decision.

Table 6.2 Options for Correcting Blow Counts (Lamb 1997)

Options of Standardizing Blow Counts to N_{60}	Advantages	Disadvantages
Multiply N values by correction factors and showing corrected N values on final boring logs	No changes to equipment, data on final boring log is correct	Creates extra office work
Provide correction factor on boring logs and let users adjust N values	No changes to equipment, simple change to final boring log	Puts responsibility of correcting N values on boring log users
Calibrate hammer systems in field to provide average transferred energy efficiency of 60%	No changes to boring log, field data and final boring log data is correct	Not in compliance with current ASTM standard, change in equipment necessary

It should also be noted here, that a technical working group composed of several states' geotechnical engineers and headed by Chris Dumas, FHWA, is currently discussing this issue and will provide input to State Highways' for their consideration. The purpose is to devise a means to determine N values that are consistent, repeatable and not rig dependent.

References

1. ASTM D 1586-99 Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils.

2. ASTM D 4633-86 (withdrawn) Standard Test Method for Stress Wave Energy Measurement for Dynamic Penetrometer Testing Systems.

3. Abou-Matar, H. and Goble G. G., "SPT Dynamic Analysis and Measurements", Journal of Geotechnical and Geoenvironmental Engineering, Vol. 123, No. 10, October 1997.

4. Bowles, J. E., "Foundation Analysis and Design" The McGraw-Hill Companies, Inc. Fifth edition, 1996.

5. Broms, B. B., and Flodin, N., "History of Soil Penetration Testing", Proceedings of the First International Symposium on Penetration Testing, Orlando, FL 1988.

6. Davidson, J. L., Maultsby, J. P. and Spoor, K. B., "Standard Penetration Test Energy Calibrations", Final report, Department of Civil Engineering, University of Florida, For Florida Department of Transportation, January 1999.

7. GRL, Inc., "SPT Hammer Energy Measurements, B-24 Skid, B-57 Truck and B-57 ATV Rigs of T.L.B. Associates, Inc.", for Potomac Crossing Consultants, 1999.

8. Kovacs, W. D. and Salomone, L. A., "SPT Hammer Energy Measurements," Journal of the Geotechnical Engineering Division. ASCE, Vol. 108, No GT 4, April 1982.

9. Kovacs, W. D. Salomone, L. A., and Yokal, F. Y., "Comparison of Energy Measurements in the Standard Penetration Test Using the Cathead and Rope Method," National Bureau of Standards Report to the US Nuclear Regulatory Commision, 1983.

10. Lamb, R., "SPT Energy Measurements with the PDA" 45th Annual Geotechnical Engineering Conference at the University of Minnesota, 1997.

11. Lamb, R., "SPT Hammer Calibration Update," a Memo to Geotechnical Engineering Section, Minnesota Department of Transportation, April 2000.

12. McGregor, J. A. and Duncan, J. M., " Performance and Use of the Standard Penetration Test In Geotechnical Engineering Practice", Center for Geotechnical Practice and Research, Virginia Polytechnic Institute, Blacksburg, VA, October 1998.

13. NAVFAC DM-7.1, "Soil Mechanics," Design Manual 7.1, Department of the Navy, May 1982.

14. Oregon Department of Transportation, "Energy Measurements on Standard Penetration Tests," Bridge Engineering Section, by Goble, Rausche, Likins and Associates, Inc., March 1995.

15. Pile Dynamics, Inc., SPT Analyzer Users Manual, Cleveland, OH, 1995.

16. Robertson, P. K. and Wride, C. E., "Cyclic Liquefaction and its Evaluation Based on the SPT and CPT", Proceedings of the National Center for Earthquake Engineering Research, NCEER, Report No 970022, 1997.

17. Schmertman, J. H., "Use the SPT to Measure Dynamic Soil Properties ?-Yes, But..!", Dynamic Geotechnical Testing, ASTM STP 654, American Society for Testing and Materials, 1978.

18. Seed, H. B., Tokimastu, K., Harder, L. F. and Chung, R. F., "Influence of SPT Procedures in Soil Liquefaction Resistance Evaluations," Journal of Geotechnical Engineering, Vol. 111, No. 12, December 1985.

19. Skempton, A. W., "Standard Penetration Test Procedures and the Effects in Sands of Overburden Pressure, Relative Density, Particle Size, Ageing and Over Consolidation", Geotechnique 36: 3, September, 1986.

APPENDIX A

Field Boring Logs

SHA 73.0-46
8-25-2000

STATE HIGHWAY ADMINISTRATION OF MARYLAND
GEOTECHNICAL EXPLORATIONS DIVISION

FOUNDATIONS BORING LOG

Contract No. AA666B21 Boring No. B-4 No. ___ of ___ Borings

Sheet 1 of 1

Description Interchange at MD Rte. 32 and Canine Road

Station *731+26 73' B/L Constr. MD 32 W.B.R.

Surface Elevation 148.64

Date Started 03/09/01

Date Completed 03/12/01

Driller A. Arnold

Rig Type CME 550

Rig No. SG80311

Hammer Drop 30 IN.

Drive Hammer -- LB.

Spoon Hammer 140 LB.

[redacted] Auger Size 3 3/8 IN.

Spoon Size 2 IN.

Size of Core -- IN.

Size of Bit -- IN.

Core Barrel Type --

Auger Depth 74'

WATER TABLE

Depth Below Surface	Time	Date
19' Water	0 Hr.	03/12/01
27' Water	24 Hr.	03/14/01

DEPTH IN FEET	MATERIAL CLASSIFICATION	SPOON SAMPLE NO.	SPOON BLOWS	SPOON DEPTH	RECOVERY	REMARKS
0.0'	Damp Loos Brown Sand Trace of Silt, Trace of Gravel (FILL)	1	1-2 3	0.0' 1.5'	18"	
4.0'						Boring moved due utilities
4.0' 9.0'	Damp medium dense Brown Sand and Gravel	2	6-10 11	4.0' 5.5'	18"	*Original Station 731+35 53'±
9.0	Damp Medium Dense White Sand	3	3-5 7	9.0' 10.5'	12"	
19.0'		4	4-8 8	14.0' 15.5'	16"	
19.0'	Wet Medium Dense Varicolored Sand	5	3-8 6	19.0' 20.5'	18"	
25.0'		6	4-7 7	24.0' 25.5'	16"	
25.0'	Damp Stiff to Hard Gray Silt	7	3-10 12	29.0' 30.5'	18"	
39.0'		8	12-16 26	34.0' 35.5'	18"	
39.0'	Wet Medium Dense To Very Dense Varicolored Sand	9	8-10 8	39.0' 40.5'	18"	
		10	7-25 35	44.0' 45.5'	16"	*Running Sand 7' In Auger
		11	10-34 50	49.0' 50.5'	16"	
59.0'		12	20-20 31	54.0' 55.5'	18"	
59.0' 64.0'	Wet Very Dense White Sand Trace Of Gravel	13	27-50 6	59.0' 60.0'	10"	*Running Sand 2' In Auger
64.0' 69.0'	Wet Very Hard Gray Silt	14	25-50 4	64'0" 64'10"	10"	
69.0'	Wet Very Dense Gray Sand, Trace Of Silt, Trace Of Gravel	15	50 5	69'0" 69'5"	3"	*Running Sand 7' In Auger
		16	50 3	74'0" 74'3"	3"	
74'3"						

DEPTH	CASING BLOWS PER FOOT
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	
23	
24	
25	
26	
27	
28	
29	
30	
31	
32	
33	
34	
35	
36	
37	
38	

SHA 73.0-46
8-25-2000

STATE HIGHWAY ADMINISTRATION
OF MARYLAND
GEOTECHNICAL EXPLORATIONS DIVISION

FOUNDATIONS BORING LOG

No. ___ of ___ Borings

Contract No. AA666B21 Boring No. B-4-1 Sheet 1 of 1

Description MD 32 and Canine Road Annalizer

Station 731+26 78' ± B/L Constr. MD 32 W.B.R.

Surface Elevation 148.64 Date Started 03/31/01

Date Completed ___

Driller ___

Rig Type B-61

Rig No. SG80216

Hammer Drop 30 IN.
Drive Hammer - LB.
Spoon Hammer 140 LB.
Casing Auger Size 2 3/8 IN.
Spoon Size 2 IN.
Size of Core - IN.
Size of Bit - IN.
Core Barrel Type -
Auger Depth -

WATER TABLE

Depth Below Surface	Time	Date

DEPTH IN FEET	MATERIAL CLASSIFICATION	SPOON SAMPLE NO.	SPOON BLOWS	SPOON DEPTH	ROCK CORE RECOVERY %	REMARKS
0.0' 4.0'	Damp, Brown Silty Sand and Gravel					
4.0' 9.0'	Damp Dense Brown Sand And Gravel	-	12 12-13	4.0' 5.5'	14"	
9.0'	Damp Medium Dense Tan Fine Sand	-	6 8-7	9.0' 10.5'	12"	
		-	7 9-10	14.0' 15.5'	9"	
23.5'		-	6 7-9	19.0' 20.5'	10"	
23.5'	Damp Very Stiff To Hard Varicolored Clayey Silt Trace OF Fine Sand	-	6 10-15	24.0' 25.5'	14"	
		-	6-13 27	29.0' 30.5'	14"	
39.0'		-	18 27-30	34.0' 35.5'	14"	
39.0'	Moist Medium Dense To Very Dense Orange Brown To Varicolored Sand Trace Of Silt	-	14 10-10	39.0' 40.5'	12"	
59.0'		-	14 25-30/5"	49'0" 50'5"	14"	
59.0'	Damp Very Hard Varicolored Silt	-	10 34-50/3"	59'6" 60'3"	10"	
72.0'		-	25 30-35	64'0" 65.5'	11"	
72.0' 74.17	Very Dense Sand And Gravel	-	50/2"	74'0" 74'2"		

DEPTH	CASING BLOWS PER FOOT
1	FLUSH
2	JOINT
3	TO
4	59.0'
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	
23	
24	
25	
26	
27	
28	
29	
30	
31	
32	
33	
34	
35	
36	
37	
38	

SHA 73.0-46
8-25-2000

STATE HIGHWAY ADMINISTRATION
OF MARYLAND
GEOTECHNICAL EXPLORATIONS DIVISION (DONUT HAMMER)

FOUNDATIONS BORING LOG

No. ___ of ___ Borings

Contract No. AA666B21 Boring No. B-4-2 Sheet 1 of 1

Description MD Interchange at MD Rte. 32 and Canine Road

Station 731+26 83' Lt. B/L MD 32 W.B.R.

Surface Elevation 148

Date Started 04/20/01

Date Completed 04/20/01

Driller L. Clarke

Rig Type B-61

Rig No. SG80216

Hammer Drop 30 IN.

Drive Hammer -- LB.

Spoon Hammer 140 LB.

~~Casing~~ Auger Size 2 3/8 IN.

Spoon Size 2 IN.

Size of Core -- IN.

Size of Bit -- IN.

Core Barrel Type --

Auger Depth 39.0'

WATER TABLE

Depth Below Surface	Time	Date
20'	08 Hrs	04/20/01
Caved @ 10'		

DEPTH IN FEET	MATERIAL CLASSIFICATION	SPOON SAMPLE NO.	SPOON BLOWS	SPOON DEPTH	ROCK CORE RECOVERY %	REMARKS
4.0' – 9'0'	Damp Medium Dense Sand and Gravel		17 8-11	4.0' 5.5'	6"	
9.0' – 20.5'	Damp Medium Dense Fine Sand		8 12-11	9.0' 10.5'	10"	
			6 10-13	14.0' 15.5'	10"	
20.5' – 25.5'	Wet Medium Dense Brown Sand, Some Gravel		5 5-7	19.0' 20.5'	15"	
25.5' – 39.0'	Damp Very Stiff To Hard Light Gray Silt No Fine Sand To Trace Of Fine Sand		4 7-10	24.0' 25.5'	14"	
			9 24-36	29.0' 30.5'	18"	
			16 24-35	34.0' 35.5'	17"	
39.0' – 40'3"	Damp Very Hard Light Gray Some Brown Fine Sandy Silt		23 35-50/3"	39'0" 40'3"	16"	

DEPTH	CASING BLOWS PER FOOT
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	
21	
22	
23	
24	
25	
26	
27	
28	
29	
30	
31	
32	
33	
34	
35	
36	
37	
38	

APPENDIX B

Field Energy Measurements

1.16	inches^2	Area
0.492083	kips/feet^3	Specific Weight Density
16807.7	feet/second	Wave Speed
29999.6	ksi	Elastic Modulus
Strain Gage Calibration Factors		
F3	F1	219.73
F4	F2	218.87
Accelerometer Calibration Factors		
A3	A1	395
A4	A2	415

PJ	MD 32
PN	B-4
PD	COLS OF BRIDGE; SHA DRILL RIG 80311; CME 550
OP	AI

Depth	N	Average ETR	Stand Dev
Feet		(%)	
5	21	77.18	2.06
11	14	77.35	1.22
15	16	78.61	3.45
20	15	78.14	2.31
25	14	81.01	2.01
31	19	87.08	1.36
41	18	89.36	1.39
46	61	79.37	2.25
52	84	79.87	1.37
61.5	27-50/6"	83.04	0.73
71	50/5"	83.02	1.55
76	50/3"	85.03	2.86

CME	550	Automatic Hammer
1.16	inches^2	Area
81	feet	Length
0.492083	kips/feet ^3	Specific Weight Density
16807.7	feet^3	kips/ Wave Speed
29999.6	second	feet/ Elastic Modulus

Strain Gage Calibration Factors

F3	F1	220
F4	F2	219

Accelerometer Calibration Factors

A3	A1	395
A4	A2	415

PJ	MD 32
PN	B-4
PD	COLS OF BRIDGE; SHA DRILL RIG 80311; CME 550
OP	AI
@50'+	sx=2

Date	Time	LP Feet	Penetration in	N	SL	ETR (%)	EF2 kip-feet	VMX feet/second	FMX kips
3/9/01	10:36:35	5	12	21	7	73.8	0.203	16.6	27
3/9/01	10:36:36	5	12	21	8	80.3	0.208	15.9	26
3/9/01	10:36:37	5	12	21	9	75.8	0.203	15.5	27
3/9/01	10:36:39	5	12	21	10	77	0.203	15.8	27
3/9/01	10:36:40	5	12	21	11	75.5	0.205	15.7	27
3/9/01	10:36:41	5	12	21	12	79.1	0.207	16.1	26
3/9/01	10:36:42	5	12	21	13	75.4	0.203	16.8	27
3/9/01	10:36:43	5	12	21	14	79.6	0.207	16	27
3/9/01	10:36:44	5	12	21	15	82.9	0.206	15.1	27
3/9/01	10:36:45	5	12	21	16	75.9	0.2	16	26
3/9/01	10:36:46	5.5	18	21	17	75.5	0.204	16.4	27
3/9/01	10:36:48	6	18	21	18	76.6	0.201	15.9	26
3/9/01	10:36:49	6	18	21	19	77.1	0.202	15.3	26
3/9/01	10:36:50	6	18	21	20	76.7	0.205	15.8	27
3/9/01	10:36:51	6	18	21	21	76	0.201	15.8	27
3/9/01	10:36:52	6	18	21	22	77.5	0.201	16.5	26
3/9/01	10:36:53	6	18	21	23	75.3	0.2	15.8	26
3/9/01	10:36:54	6	18	21	24	77.4	0.203	16.2	26
3/9/01	10:36:55	6	18	21	25	76.5	0.199	15.7	27
3/9/01	10:36:56	6	18	21	26	78.2	0.201	15.6	25
3/9/01	10:36:58	6	18	21	27	78.7	0.202	15.3	26

Automatic Hammer MD Rte.
CME 550

3/9/01	11:01:20	9.5	12	14	31	76.3	0.25	15.6	27
3/9/01	11:01:21	9.5	12	14	32	80.2	0.251	15.8	27
3/9/01	11:01:22	9.5	12	14	33	78.1	0.253	16.1	28
3/9/01	11:01:23	9.5	12	14	34	76.8	0.25	16	27
3/9/01	11:01:24	9.5	12	14	35	77.1	0.249	16	27
3/9/01	11:01:25	9.5	18	14	36	78.1	0.253	16.2	28
3/9/01	11:01:27	10	18	14	37	78.7	0.251	16.1	28
3/9/01	11:01:28	10	18	14	38	77.9	0.247	15.5	27
3/9/01	11:01:29	10	18	14	39	76.8	0.247	15.7	27
3/9/01	11:01:30	10	18	14	40	77	0.246	15.7	27
3/9/01	11:01:31	10	18	14	41	76.7	0.246	15.8	27
3/9/01	11:01:32	10	18	14	42	77.3	0.246	15.8	27
3/9/01	11:01:33	10	18	14	43	75	0.241	16	27
3/9/01	11:01:35	10.5	18	14	44	76.9	0.244	16.1	28
3/9/01	11:16:04	15	12	16	49	81.3	0.251	15.6	25
3/9/01	11:16:05	15	12	16	50	78.2	0.246	15.4	26
3/9/01	11:16:06	15	12	16	51	77.4	0.248	16	26
3/9/01	11:16:08	15	12	16	52	76.6	0.248	16.4	26
3/9/01	11:16:09	15	12	16	53	76.6	0.245	16.8	25
3/9/01	11:16:10	15	12	16	54	75.7	0.245	16.8	25
3/9/01	11:16:11	15.5	12	16	55	75.5	0.245	16.7	26
3/9/01	11:16:12	16	12	16	56	75.6	0.248	16.3	27
3/9/01	11:16:14	16	18	16	57	74.2	0.243	16	25
3/9/01	11:16:15	16	18	16	58	78.9	0.242	15.8	25
3/9/01	11:16:16	16	18	16	59	77.6	0.247	16.2	25
3/9/01	11:16:17	16	18	16	60	78.5	0.247	15.9	26
3/9/01	11:16:18	16	18	16	61	81.3	0.244	15.9	26
3/9/01	11:16:19	16	18	16	62	87.3	0.248	16.4	26
3/9/01	11:16:21	16	18	16	63	78.8	0.244	14.6	26
3/9/01	11:16:22	16.5	18	16	64	84.2	0.245	15.9	26
3/9/01	11:31:04	20	12	15	69	79.6	0.266	15.5	27
3/9/01	11:31:05	20	12	15	70	76.9	0.263	15.4	25
3/9/01	11:31:06	20	12	15	71	81.6	0.263	15	27
3/9/01	11:31:07	20	12	15	72	78.8	0.265	14.2	25
3/9/01	11:31:09	20	12	15	73	81	0.269	14.2	27
3/9/01	11:31:10	20	12	15	74	79.6	0.263	14.7	27
3/9/01	11:31:11	20	12	15	75	79.3	0.263	14.5	27
3/9/01	11:31:12	20.5	12	15	76	79.9	0.267	14.4	26
3/9/01	11:31:13	20.5	18	15	77	76.5	0.263	14.2	27
3/9/01	11:31:14	20.5	18	15	78	78.1	0.265	14.4	27
3/9/01	11:31:16	20.5	18	15	79	78	0.262	14.7	25
3/9/01	11:31:17	20.5	18	15	80	74.8	0.261	15.1	26
3/9/01	11:31:18	20.5	18	15	81	73.6	0.26	15.9	26
3/9/01	11:31:19	21	18	15	82	76.2	0.262	16.2	26
3/9/01	11:47:14	24.5	12	14	87	84	0.263	16.4	25
3/9/01	11:47:15	24.5	12	14	88	82	0.259	16.4	26

Automatic Hammer MD Rte.
CME 550

3/9/01	11:47:16	24.5	12	14	89	80.8	0.254	15.9	25
3/9/01	11:47:17	24.5	12	14	90	78.7	0.251	15.9	25
3/9/01	11:47:18	24.5	12	14	91	80	0.253	16.5	24
3/9/01	11:47:20	25	12	14	92	79.6	0.252	16.3	25
3/9/01	11:47:21	25.5	12	14	93	81.1	0.252	16.4	24
3/9/01	11:47:22	25.5	18	14	94	80.1	0.249	16.8	24
3/9/01	11:47:23	25.5	18	14	95	81	0.251	17	24
3/9/01	11:47:24	25.5	18	14	96	80.5	0.248	17.3	24
3/9/01	11:47:25	25.5	18	14	97	81.8	0.252	17.5	24
3/9/01	11:47:26	25.5	18	14	98	77.8	0.247	18	24
3/9/01	11:47:27	25.5	18	14	99	81	0.253	18.1	23
3/9/01	11:47:28	26	18	14	100	85.7	0.243	18	23
3/9/01	11:57:38	30	12	19	104	86.5	0.279	15.7	27
3/9/01	11:57:39	30	12	19	105	89.8	0.285	15.4	27
3/9/01	11:57:41	30	12	19	106	85.5	0.279	15.3	27
3/9/01	11:57:42	30	12	19	107	86.3	0.282	16.3	27
3/9/01	11:57:43	30	12	19	108	86.1	0.283	15.3	27
3/9/01	11:57:44	30	12	19	109	87.3	0.282	15.6	27
3/9/01	11:57:45	30	12	19	110	86.7	0.284	15.4	27
3/9/01	11:57:46	30.5	18	19	111	88.9	0.285	15.7	27
3/9/01	11:57:47	30.5	18	19	112	86.3	0.279	16.4	27
3/9/01	11:57:49	30.5	18	19	113	88.6	0.284	16	27
3/9/01	11:57:50	30.5	18	19	114	85.4	0.279	16	27
3/9/01	11:57:54	30.5	18	19	115	88	0.284	16.4	27
3/9/01	11:57:55	30.5	18	19	116	84.5	0.278	16.3	27
3/9/01	11:57:56	30.5	18	19	117	88.3	0.285	17.4	27
3/9/01	11:57:58	30.5	18	19	118	87.2	0.279	16.7	27
3/9/01	11:57:59	30.5	18	19	119	87.8	0.285	18	27
3/9/01	11:58:00	30.5	18	19	120	86.6	0.279	16.9	27
3/9/01	11:58:01	30.5	18	19	121	88.5	0.289	18.2	28
3/9/01	11:58:02	30.5	18	19	122	86.3	0.28	16.8	27
3/9/01	13:50:06	39.5	12	18	185	88.4	0.3	15.1	28
3/9/01	13:50:07	39.5	12	18	186	87.9	0.301	15.2	28
3/9/01	13:50:08	39.5	12	18	187	90.1	0.304	15.2	28
3/9/01	13:50:09	39.5	12	18	188	87.3	0.297	15.2	28
3/9/01	13:50:10	39.5	12	18	189	90.9	0.302	15.6	28
3/9/01	13:50:11	39.5	12	18	190	88.1	0.307	15.8	28
3/9/01	13:50:13	39.5	12	18	191	90.3	0.305	15.3	28
3/9/01	13:50:14	39.5	12	18	192	88.9	0.302	15.8	28
3/9/01	13:50:15	39.5	12	18	193	90.2	0.306	16	28
3/9/01	13:50:16	39.5	12	18	194	90.9	0.309	15.8	28
3/9/01	13:50:17	39.5	18	18	195	91.5	0.307	15.9	28
3/9/01	13:50:18	40	18	18	196	88.7	0.301	16.1	28
3/9/01	13:50:19	40	18	18	197	89.6	0.305	16	28
3/9/01	13:50:20	40	18	18	198	89.4	0.3	16	28
3/9/01	13:50:22	40	18	18	199	88.6	0.303	16	28

3/9/01	13:50:23	40	18	18	200	86.9	0.296	15.8	28
3/9/01	13:50:24	40	18	18	201	91.6	0.314	16	28
3/12/01	9:02:54	44.5	12	61	211	77.6	0.3	12.1	26
3/12/01	9:02:55	44.5	12	61	212	76.9	0.303	12.4	25
3/12/01	9:02:56	44.5	12	61	213	76.8	0.298	12.2	27
3/12/01	9:02:57	44.5	12	61	214	78.9	0.304	12.5	25
3/12/01	9:02:58	44.5	12	61	215	75.4	0.302	12.4	26
3/12/01	9:03:00	44.5	12	61	216	78	0.303	12.3	26
3/12/01	9:03:01	44.5	12	61	217	76.6	0.299	12.4	26
3/12/01	9:03:02	44.5	12	61	218	78	0.305	12.3	26
3/12/01	9:03:03	44.5	12	61	219	77.5	0.3	12.5	26
3/12/01	9:03:04	44.5	12	61	220	79	0.31	12.6	25
3/12/01	9:03:05	44.5	12	61	221	77.5	0.303	12.6	26
3/12/01	9:03:06	44.5	12	61	222	76.5	0.298	12.1	26
3/12/01	9:03:07	44.5	12	61	223	78.5	0.3	12.4	25
3/12/01	9:03:08	44.5	12	61	224	75.4	0.304	12.4	26
3/12/01	9:03:09	44.5	12	61	225	76.8	0.273	12.3	26
3/12/01	9:03:10	44.5	12	61	226	78.7	0.302	12.2	26
3/12/01	9:03:11	44.5	12	61	227	76.6	0.299	12.2	26
3/12/01	9:03:12	44.5	12	61	228	76.3	0.304	12.4	25
3/12/01	9:03:13	44.5	12	61	229	75.8	0.297	12.1	26
3/12/01	9:03:15	44.5	12	61	230	78.5	0.303	12.4	25
3/12/01	9:03:16	44.5	12	61	231	77.2	0.3	12.5	26
3/12/01	9:03:17	44.5	12	61	232	78.7	0.306	12.6	26
3/12/01	9:03:18	44.5	12	61	233	76.9	0.301	12.5	27
3/12/01	9:03:19	44.5	12	61	234	79.8	0.306	12.6	26
3/12/01	9:03:20	45	12	61	235	75	0.298	12.5	26
3/12/01	9:03:21	45	18	61	236	76.7	0.301	12.5	26
3/12/01	9:03:22	45	18	61	237	78.7	0.3	12.4	27
3/12/01	9:03:23	45	18	61	238	76.3	0.306	12.5	25
3/12/01	9:03:24	45	18	61	239	80.1	0.298	12.2	26
3/12/01	9:03:25	45	18	61	240	80.6	0.3	12.4	25
3/12/01	9:03:26	45	18	61	241	78.9	0.296	12.3	26
3/12/01	9:03:27	45	18	61	242	81.8	0.273	12	24
3/12/01	9:03:28	45	18	61	243	81	0.27	12	25
3/12/01	9:03:31	45	18	61	245	80.5	0.293	11.5	25
3/12/01	9:03:32	45	18	61	246	81.8	0.299	12.1	24
3/12/01	9:03:33	45	18	61	247	82.5	0.291	11.7	25
3/12/01	9:03:34	45	18	61	248	82	0.294	12.1	24
3/12/01	9:03:35	45	18	61	249	82.2	0.292	12.2	24
3/12/01	9:03:36	45	18	61	250	82.1	0.295	12	24
3/12/01	9:03:37	45	18	61	251	80.8	0.282	11.6	24
3/12/01	9:03:38	45	18	61	252	81.9	0.294	12.1	26
3/12/01	9:03:39	45	18	61	253	80.9	0.267	11.9	25
3/12/01	9:03:40	45	18	61	254	82.5	0.295	11.9	23
3/12/01	9:03:41	45	18	61	255	81.1	0.288	12	24

Automatic Hammer MD Rte.
CME 550

3/12/01	9:03:42	45	18	61	256	81.1	0.291	12	24
3/12/01	9:03:44	45	18	61	257	81.3	0.286	12.1	24
3/12/01	9:03:45	45	18	61	258	81.5	0.293	12	24
3/12/01	9:03:46	45	18	61	259	80.2	0.285	12	24
3/12/01	9:03:47	45	18	61	260	82.3	0.291	12.1	25
3/12/01	9:03:48	45	18	61	261	80.7	0.287	11.6	25
3/12/01	9:03:49	45	18	61	262	81.9	0.291	11.8	24
3/12/01	9:03:50	45	18	61	263	80.8	0.284	11.9	25
3/12/01	9:03:51	45	18	61	264	79.7	0.29	11.9	24
3/12/01	9:03:52	45	18	61	265	80.6	0.285	12	25
3/12/01	9:03:53	45	18	61	266	80.5	0.289	11.9	24
3/12/01	9:03:54	45	18	61	267	81.3	0.286	12.1	24
3/12/01	9:03:55	45	18	61	268	80.8	0.292	11.9	26
3/12/01	9:03:56	45.5	18	61	269	81.6	0.289	12.1	25
3/12/01	9:03:57	45.5	18	61	270	83.7	0.304	12.4	27
3/12/01	9:37:16	49.5	12	84	277	76	0.272	12.7	26
3/12/01	9:37:18	49.5	12	84	278	78.1	0.274	12.7	25
3/12/01	9:37:20	49.5	12	84	279	77.7	0.274	13	25
3/12/01	9:37:23	49.5	12	84	280	78.2	0.27	13.1	24
3/12/01	9:37:25	49.5	12	84	281	78.1	0.268	13.7	24
3/12/01	9:37:27	49.5	12	84	282	79.5	0.266	13.7	24
3/12/01	9:37:29	49.5	12	84	283	79	0.27	13.9	24
3/12/01	9:37:32	49.5	12	84	284	80.4	0.269	13.9	24
3/12/01	9:37:34	49.5	12	84	285	79.3	0.258	13.9	24
3/12/01	9:37:36	49.5	12	84	286	78.8	0.264	13.4	24
3/12/01	9:37:38	49.5	12	84	287	80.8	0.275	13.4	24
3/12/01	9:37:40	49.5	12	84	288	79.6	0.274	13.6	25
3/12/01	9:37:43	49.5	12	84	289	80.9	0.277	13.5	25
3/12/01	9:37:45	49.5	12	84	290	80	0.271	13.5	24
3/12/01	9:37:47	49.5	12	84	291	79.8	0.26	13.6	25
3/12/01	9:37:49	49.5	18	84	292	80.7	0.271	13.8	25
3/12/01	9:37:52	50.5	18	84	293	80.9	0.268	13.1	24
3/12/01	9:37:54	50.5	18	84	294	81.9	0.262	14.2	25
3/12/01	9:37:56	50.5	18	84	295	80.1	0.275	13.6	24
3/12/01	9:37:58	50.5	18	84	296	80.5	0.271	13.6	25
3/12/01	9:38:00	50.5	18	84	297	80.1	0.272	13.3	25
3/12/01	9:38:03	50.5	18	84	298	79.3	0.259	13.8	25
3/12/01	9:38:05	50.5	18	84	299	80.3	0.269	13.3	24
3/12/01	9:38:07	50.5	18	84	300	81.7	0.268	13.4	24
3/12/01	9:38:09	50.5	18	84	301	80.1	0.269	13.8	24
3/12/01	9:38:12	50.5	18	84	302	80.4	0.253	13.4	24
3/12/01	9:38:14	50.5	18	84	303	79.9	0.256	13.5	24
3/12/01	9:38:16	50.5	18	84	304	81.2	0.255	13.3	24
3/12/01	9:38:18	50.5	18	84	305	82.7	0.27	13.5	24
3/12/01	9:38:20	50.5	18	84	306	81.5	0.264	13.4	24
3/12/01	9:38:23	50.5	18	84	307	81.9	0.256	13.7	25

Automatic Hammer MD Rte.
CME 550

3/12/01	9:38:25	50.5	18	84	308	80.4	0.266	13.1	24
3/12/01	9:38:27	50.5	18	84	309	80.4	0.269	13.4	25
3/12/01	9:38:29	50.5	18	84	310	79.7	0.259	13	27
3/12/01	9:38:32	50.5	18	84	311	80.4	0.266	13.3	26
3/12/01	9:38:34	50.5	18	84	312	81.5	0.269	13.1	25
3/12/01	9:38:36	50.5	18	84	313	79.1	0.271	13.1	27
3/12/01	9:38:38	50.5	18	84	314	80.6	0.27	13.1	25
3/12/01	9:38:40	50.5	18	84	315	78.4	0.272	13.8	26
3/12/01	9:38:43	50.5	18	84	316	80	0.269	12.7	27
3/12/01	9:38:45	50.5	18	84	317	79.1	0.267	13.8	25
3/12/01	9:38:47	50.5	18	84	318	78.6	0.249	13.2	25
3/12/01	11:31:43	59.5	12	27-50/6"	333	83.8	0.258	13.3	22
3/12/01	11:31:45	59.5	12	27-50/6"	334	83.3	0.254	13	22
3/12/01	11:31:47	59.5	12	27-50/6"	335	83.9	0.257	12.9	23
3/12/01	11:31:50	59.5	12	27-50/6"	336	82.2	0.262	13.1	24
3/12/01	11:31:52	59.5	12	27-50/6"	337	81.7	0.253	13.2	22
3/12/01	11:31:54	59.5	12	27-50/6"	338	84	0.263	12.7	25
3/12/01	11:31:56	59.5	12	27-50/6"	339	82.6	0.259	13	24
3/12/01	11:31:59	59.5	12	27-50/6"	340	82.8	0.258	12.8	24
3/12/01	11:32:01	59.5	12	27-50/6"	341	83.3	0.256	13	24
3/12/01	11:32:03	59.5	12	27-50/6"	342	83.3	0.256	13.3	24
3/12/01	11:32:06	59.5	12	27-50/6"	343	82.9	0.26	13.3	23
3/12/01	11:32:08	59.5	12	27-50/6"	344	83.2	0.255	13.6	23
3/12/01	11:32:10	59.5	12	27-50/6"	345	82.2	0.255	13.6	22
3/12/01	11:32:13	59.5	12	27-50/6"	346	83.1	0.262	13.5	23
3/12/01	11:32:15	59.5	12	27-50/6"	347	83.9	0.262	13.9	23
3/12/01	11:32:17	59.5	12	27-50/6"	348	84.7	0.265	13.8	24
3/12/01	11:32:19	59.5	12	27-50/6"	349	82.9	0.255	13.5	24
3/12/01	11:32:22	59.5	12	27-50/6"	350	83.8	0.268	13.4	26
3/12/01	11:32:24	59.5	12	27-50/6"	351	82.2	0.265	13.5	25
3/12/01	11:32:26	59.5	12	27-50/6"	352	82.4	0.26	13.4	25
3/12/01	11:32:29	59.5	12	27-50/6"	353	82.2	0.266	13.4	25
3/12/01	11:32:31	59.5	12	27-50/6"	354	82.9	0.265	13.5	25
3/12/01	11:32:33	59.5	12	27-50/6"	355	83.2	0.262	13.8	24
3/12/01	11:32:36	59.5	12	27-50/6"	356	82.5	0.264	13.5	25
3/12/01	14:15:55	69	5	50/5"	357	84.5	0.26	13.8	26
3/12/01	14:15:57	69	5	50/5"	358	83	0.256	13.7	25
3/12/01	14:16:00	69	5	50/5"	359	85.8	0.258	13.7	25
3/12/01	14:16:02	69	5	50/5"	360	85.3	0.26	13.8	24
3/12/01	14:16:04	69	5	50/5"	361	84	0.255	14.1	23
3/12/01	14:16:07	69	5	50/5"	362	85.7	0.254	14.5	23
3/12/01	14:16:09	69	5	50/5"	363	85.5	0.251	14.2	23
3/12/01	14:16:11	69	5	50/5"	364	85.3	0.251	14.3	23
3/12/01	14:16:14	69	5	50/5"	365	83	0.247	13.8	23
3/12/01	14:16:16	69	5	50/5"	366	82.4	0.247	14.3	22
3/12/01	14:16:18	69	5	50/5"	367	81.8	0.247	14.3	22

Automatic				Hammer				MD	Rte.
CME 550									
3/12/01	14:16:21	69	5	50/5"	368	83.3	0.249	14.2	22
3/12/01	14:16:23	69	5	50/5"	369	82.6	0.248	14	22
3/12/01	14:16:25	69	5	50/5"	370	82.9	0.247	14	22
3/12/01	14:16:28	69	5	50/5"	371	81.6	0.243	13.5	22
3/12/01	14:16:30	69	5	50/5"	372	83	0.248	13.7	21
3/12/01	14:16:32	69	5	50/5"	373	82.9	0.245	13.8	21
3/12/01	14:16:35	69	5	50/5"	374	82.3	0.246	14.4	22
3/12/01	14:16:37	69	5	50/5"	375	82.9	0.245	13.6	22
3/12/01	14:16:39	69	5	50/5"	376	81	0.243	13.7	22
3/12/01	14:16:42	69	5	50/5"	377	81.3	0.248	14.7	22
3/12/01	14:16:44	69	5	50/5"	378	81.2	0.245	14.4	22
3/12/01	14:16:46	69	5	50/5"	379	81.6	0.242	14.5	23
3/12/01	14:16:49	69	5	50/5"	380	81.7	0.247	14.6	23
3/12/01	14:16:51	69	5	50/5"	381	82.7	0.244	14.8	22
3/12/01	14:16:53	69	5	50/5"	382	80.5	0.249	14.7	22
3/12/01	14:51:57	74	3	50/3"	383	91.9	0.294	13.2	28
3/12/01	14:51:59	74	3	50/3"	384	88.8	0.291	13.2	27
3/12/01	14:52:01	74	3	50/3"	385	89.7	0.287	13.3	27
3/12/01	14:52:05	74	3	50/3"	386	89.5	0.282	13.5	26
3/12/01	14:52:07	74	3	50/3"	387	90.7	0.283	13.5	26
3/12/01	14:52:09	74	3	50/3"	388	88.5	0.281	13.3	26
3/12/01	14:52:11	74	3	50/3"	389	86.4	0.274	13	26
3/12/01	14:52:13	74	3	50/3"	390	86	0.272	12.8	25
3/12/01	14:52:15	74	3	50/3"	391	86.6	0.271	13.3	25
3/12/01	14:52:17	74	3	50/3"	392	84.3	0.261	12.6	24
3/12/01	14:52:19	74	3	50/3"	393	83.7	0.269	12.8	26
3/12/01	14:52:21	74	3	50/3"	394	83.8	0.273	12.9	25
3/12/01	14:52:24	74	3	50/3"	395	82.5	0.27	12.4	25
3/12/01	14:52:26	74	3	50/3"	396	82.5	0.271	12.9	25
3/12/01	14:52:30	74	3	50/3"	398	83.7	0.27	12.8	26
3/12/01	14:52:32	74	3	50/3"	399	83.2	0.272	12.5	25
3/12/01	14:52:34	74	3	50/3"	400	84.4	0.272	13	26
3/12/01	14:52:36	74	3	50/3"	401	82.9	0.274	13	27
3/12/01	14:52:38	74	3	50/3"	402	83.9	0.275	13.1	27
3/12/01	14:52:42	74	3	50/3"	404	85	0.275	12.8	27
3/12/01	14:52:44	74	3	50/3"	405	84.4	0.271	12.4	26
3/12/01	14:52:46	74	3	50/3"	406	83.9	0.268	13	26
3/12/01	14:52:48	74	3	50/3"	407	84.2	0.272	12.7	26
3/12/01	14:52:51	74	3	50/3"	408	82.3	0.266	12.8	25
3/12/01	14:52:53	74	3	50/3"	409	83.9	0.273	12.8	26
3/12/01	14:52:55	74.5	3	50/3"	410	83.1	0.273	13.1	27
3/12/01	14.52:57	75	3	50/3"	411	79.70	268	13.2	27

1.16	inches^2	Area	
0.492083	kips/feet^3	Specific Weight Density	
16807.7	feet/second	Wave Speed	
29999.6	ksi	Elastic Modulus	
Strain Gage Calibration Factors			
F3	F1	219.73	
F4	F2	218.87	
Accelerometer		Calibration	Factors
A3	A1	395	
A4	A2	415	

PJ	MD 32
PN	B-4-1
PD	COLS OF BRIDGE; SAFETY; MOBILE B61
OP	LINWOOD

Depth	N	Average ETR	Stand Dev
Feet		(%)	
5	25	78.71	3.78
10	16	74.65	7.08
15	19	70.17	2.55
20	16	73.11	4.25
25	25	72.34	2.36
30	45	77.02	3.92
35	56	74.69	2.54
40	20	72.67	2.39
49.7	25-50/2”	79.02	7.79
59.7	34-50/3”	59.42	3.79
65	62	60.69	1.53
73.7	50/2”	70.02	2.74
	Total Ave	70.23	8.53

1.16	inchesl^2	Area
34	feet	Length
0.492083	kips/ feetl^3	Specific Weight Density
16807.7	feet/ second	Wave Speed
29999.6	ksi	Elastic Modulus
Strain	Gage	Calibration Factors
F3	F1	220
F4	F2	219
Accelerometer Calibration Factors		
A3	A1	395
A4	A2	415

PJ	MD 32
PN	B-4-1
PD	COLS OF BRIDGE; SAFETY; MOBILE B61
OP	LINWOOD

Date	Time	LP Feet	Penetration in	N	SL	ETR (%)	EF2 kip-feet	VMX feet/second	FMX kips
3/31/01	10:47:45	10	12	16	28	72	0.215	15	0.72
3/31/01	10:47:47	10	12	16	29	70.5	0.215	16.4	0.64
3/31/01	10:47:48	10	12	16	30	65.5	0.216	15.9	0.12
3/31/01	10:47:50	10	12	16	31	77.5	0.221	15.9	0.84
3/31/01	10:47:52	10	12	16	32	71.1	0.223	15.7	0.31
3/31/01	10:47:53	10	12	16	33	73.5	0.231	16.2	0.23
3/31/01	10:47:55	10	12	16	34	73.5	0.226	15.8	0.24
3/31/01	10:47:57	10	18	16	35	73.5	0.231	15.5	-0.11
3/31/01	10:47:58	10.5	18	16	36	73.8	0.227	15.1	0.03
3/31/01	10:48:00	10.5	18	16	37	68.4	0.223	14.5	-1.03
3/31/01	10:48:02	10.5	18	16	38	76	0.236	15.3	0.04
3/31/01	10:48:03	10.5	18	16	39	93.8	0.228	15.2	1.56
3/31/01	10:48:05	10.5	18	16	40	73.9	0.23	14.2	0.33
3/31/01	10:48:07	10.5	18	16	41	70.3	0.227	14.4	-0.82
3/31/01	10:48:08	10.5	18	16	42	86.5	0.218	14.2	1.37
3/31/01	11:07:26	15	12	19	53	67.1	0.212	13.2	0.35
3/31/01	11:07:28	15.5	12	19	54	68.7	0.205	12.5	0.72
3/31/01	11:07:30	15.5	12	19	55	71.9	0.216	13.2	0.59
3/31/01	11:07:31	15.5	12	19	56	70	0.209	13.1	0.72
3/31/01	11:07:33	15.5	12	19	57	66.6	0.195	12.4	0.69
3/31/01	11:07:34	15.5	12	19	58	70.8	0.211	13.1	0.62
3/31/01	11:07:36	15.5	12	19	59	71.7	0.205	12.7	0.86
3/31/01	11:07:38	15.5	12	19	60	72.4	0.215	13.1	0.47
3/31/01	11:07:39	15.5	12	19	61	72	0.213	12.9	0.67

3/31/01	11:07:41	16	18	19	62	70.8	0.21	13	0.71
3/31/01	11:07:42	16	18	19	63	65.7	0.205	13.1	0.31
3/31/01	11:07:44	16	18	19	64	70.1	0.212	13.1	0.54
3/31/01	11:07:45	16	18	19	65	69.2	0.212	13.1	0.35
3/31/01	11:07:47	16	18	19	66	71.6	0.216	13.5	0.57
3/31/01	11:07:49	16	18	19	67	70.7	0.216	13.4	0.46
3/31/01	11:07:50	16	18	19	68	76.2	0.218	13.5	0.63
3/31/01	11:07:52	16	18	19	69	66.6	0.211	13.2	0.08
3/31/01	11:07:53	16	18	19	70	68.9	0.202	12.9	0.63
3/31/01	11:07:55	16	18	19	71	72.3	0.213	13.5	0.6
3/31/01	11:23:36	19.5	12	16	78	60	0.221	11.7	-0.25
3/31/01	11:23:38	19.5	12	16	79	74.8	0.236	13.1	1.28
3/31/01	11:23:39	19.5	12	16	80	70.3	0.232	12.9	0.97
3/31/01	11:23:41	19.5	12	16	81	73.2	0.243	13.2	0.96
3/31/01	11:23:42	19.5	12	16	82	74.6	0.25	13.5	0.99
3/31/01	11:23:44	19.5	12	16	83	71.3	0.247	12.8	0.55
3/31/01	11:23:45	19.5	12	16	84	78.7	0.255	13.6	0.91
3/31/01	11:23:47	20	18	16	85	75.6	0.257	13.3	0.58
3/31/01	11:23:49	20	18	16	86	72.2	0.245	13	0.54
3/31/01	11:23:50	20	18	16	87	70.9	0.253	13	0.35
3/31/01	11:23:52	20	18	16	88	75	0.247	12.7	0.86
3/31/01	11:23:53	20	18	16	89	76.5	0.254	13.2	0.6
3/31/01	11:23:55	20	18	16	90	76.3	0.245	13.1	0.79
3/31/01	11:23:57	20	18	16	91	73	0.246	13.3	0.54
3/31/01	11:23:58	20	18	16	92	76.3	0.249	13.5	0.65
3/31/01	11:24:00	20	18	16	93	71.1	0.242	13.3	0.27
3/31/01	11:45:32	24	12	25	100	71.1	0.255	12.6	0.73
3/31/01	11:45:34	24.5	12	25	101	69.1	0.247	12.4	0.56
3/31/01	11:45:35	24.5	12	25	102	69	0.246	12.3	0.54
3/31/01	11:45:37	24.5	12	25	103	70.7	0.254	12.5	0.61
3/31/01	11:45:39	24.5	12	25	104	67.2	0.242	12.2	0.26
3/31/01	11:45:40	24.5	12	25	105	69.6	0.245	12.3	0.48
3/31/01	11:45:42	24.5	12	25	106	70.8	0.253	12.6	0.27
3/31/01	11:45:43	24.5	12	25	107	72.1	0.256	12.5	0.38
3/31/01	11:45:45	24.5	12	25	108	71.8	0.256	12.7	0.21
3/31/01	11:45:46	24.5	12	25	109	72.7	0.261	12.5	0.15
3/31/01	11:45:48	24.5	18	25	110	72.8	0.262	12.7	-0.04
3/31/01	11:45:50	25	18	25	111	72.4	0.255	12.6	0.13
3/31/01	11:45:51	25	18	25	112	72.4	0.256	12.5	0.01
3/31/01	11:45:53	25	18	25	113	69.6	0.247	12.4	-0.08
3/31/01	11:45:54	25	18	25	114	72.2	0.253	12.5	0.17
3/31/01	11:45:56	25	18	25	115	73.4	0.258	12.4	0.11
3/31/01	11:45:57	25	18	25	116	73.4	0.259	12.6	-0.05
3/31/01	11:45:59	25	18	25	117	72.8	0.259	12.5	-0.06
3/31/01	11:46:00	25	18	25	118	74.4	0.265	12.7	0.1
3/31/01	11:46:02	25	18	25	119	76.7	0.267	12.7	0.33

3/31/01	11:46:03	25	18	25	120	74	0.264	12.4	0.04
3/31/01	11:46:05	25	18	25	121	74.4	0.269	12.6	-0.05
3/31/01	11:46:06	25	18	25	122	75.8	0.274	12.8	0.3
3/31/01	11:46:08	25	18	25	123	76.4	0.279	12.9	-0.02
3/31/01	11:46:10	25	18	25	124	73.6	0.266	12.7	0.05
3/31/01	12:15:47	29.5	12	45	131	73.1	0.256	12.2	0.51
3/31/01	12:15:48	30	12	45	132	76.3	0.269	13	0.35
3/31/01	12:15:50	30.5	12	45	133	77.1	0.27	13.1	0.43
3/31/01	12:15:52	30.5	12	45	134	68.4	0.242	12.4	0.07
3/31/01	12:15:53	30.5	12	45	135	80.7	0.259	13.2	0.6
3/31/01	12:15:55	30.5	12	45	136	80.8	0.262	13.3	0.52
3/31/01	12:15:57	30.5	12	45	137	82.3	0.267	13.3	0.46
3/31/01	12:15:58	30.5	12	45	138	79.1	0.258	13.1	0.33
3/31/01	12:16:00	30.5	12	45	139	81.1	0.26	13	0.44
3/31/01	12:16:01	30.5	12	45	140	81.3	0.262	13.1	0.18
3/31/01	12:16:03	30.5	12	45	141	84.6	0.272	13.5	0.38
3/31/01	12:16:05	30.5	12	45	142	83.4	0.267	13.2	0.21
3/31/01	12:16:06	30.5	12	45	143	81.7	0.265	13.5	0.3
3/31/01	12:16:08	31	18	45	144	79.8	0.271	13.1	0.03
3/31/01	12:16:10	31	18	45	145	79.9	0.268	13	0.05
3/31/01	12:16:11	31	18	45	146	79.4	0.267	12.7	-0.02
3/31/01	12:16:13	31	18	45	147	76.9	0.263	12.7	-0.17
3/31/01	12:16:14	31	18	45	148	79.3	0.271	13	0.03
3/31/01	12:16:16	31	18	45	149	74.6	0.261	12.7	0.2
3/31/01	12:16:18	31	18	45	150	76.9	0.27	12.9	0.04
3/31/01	12:16:19	31	18	45	151	75.2	0.259	12.9	0.48
3/31/01	12:16:21	31	18	45	152	73.7	0.258	12.8	-0.17
3/31/01	12:16:23	31	18	45	153	72.4	0.253	12.5	-0.1
3/31/01	12:16:24	31	18	45	154	75.9	0.263	12.7	0.07
3/31/01	12:16:26	31	18	45	155	76.5	0.261	12.7	-0.23
3/31/01	12:16:28	31	18	45	156	72.8	0.251	12.4	-0.04
3/31/01	12:16:29	31	18	45	157	71.8	0.241	12.3	0.26
3/31/01	12:16:31	31	18	45	158	70.4	0.242	12.2	-0.06
3/31/01	12:16:33	31	18	45	159	72.1	0.247	12.4	0.02
3/31/01	12:16:34	31	18	45	160	77.2	0.258	12.7	-0.01
3/31/01	12:16:36	31	18	45	161	73.3	0.252	12.5	-0.26
3/31/01	12:16:38	31	18	45	162	74.9	0.258	12.6	-0.2
3/31/01	12:16:39	31	18	45	163	80.7	0.269	13	0.24
3/31/01	12:16:41	31	18	45	164	76.6	0.262	12.7	-0.11
3/31/01	12:16:43	31	18	45	165	75.5	0.257	12.6	-0.14
3/31/01	12:41:53	35	12	56	184	76.7	0.25	13.8	0.09
3/31/01	12:41:54	35	12	56	185	73.9	0.233	13.5	0.2
3/31/01	12:41:55	35	12	56	186	76.1	0.241	13.6	0.3
3/31/01	12:41:57	35	12	56	187	74.3	0.234	13.6	0.28
3/31/01	12:41:58	35	12	56	188	72.3	0.233	13.4	-0.33
3/31/01	12:42:00	35	12	56	189	75.4	0.23	13.3	0.39

3/31/01	12:42:01	35	12	56	190	73.2	0.23	13.3	0.14
3/31/01	12:42:03	35	12	56	191	76	0.237	13.5	0.16
3/31/01	12:42:04	35	12	56	192	74.9	0.239	13.6	0.04
3/31/01	12:42:05	35	12	56	193	77.8	0.246	13.7	0.22
3/31/01	12:42:07	35	12	56	194	75.3	0.24	13.6	0.18
3/31/01	12:42:08	35	12	56	195	74.5	0.239	13.6	-0.04
3/31/01	12:42:10	35	12	56	196	72.4	0.233	13.5	-0.25
3/31/01	12:42:11	35	12	56	197	71.2	0.23	13.4	-0.1
3/31/01	12:42:12	35	12	56	198	77.2	0.233	13.6	0.51
3/31/01	12:42:14	35	12	56	199	75	0.232	13.3	0.24
3/31/01	12:42:15	35	12	56	200	78.6	0.244	13.7	0.23
3/31/01	12:42:16	35	12	56	201	79.1	0.237	13.5	0.53
3/31/01	12:42:18	35	12	56	202	78.4	0.239	13.5	0.64
3/31/01	12:42:19	35	12	56	203	78.9	0.245	13.7	-0.04
3/31/01	12:42:21	35	12	56	204	75.3	0.235	13.5	0.07
3/31/01	12:42:22	35	12	56	205	80.7	0.243	13.9	0.28
3/31/01	12:42:23	35	12	56	206	75	0.229	13.4	-0.01
3/31/01	12:42:25	35	12	56	207	79.2	0.236	13.6	0.66
3/31/01	12.42:26	35	12	56	208	75.7	0.233	13.5	0.28
3/31/01	12:42:28	35	12	56	209	72.7	0.23	13.3	-0.14
3/31/01	12:42:29	35.5	12	56	210	76.5	0.234	13.7	-0.2
3/31/01	12:42:31	35.5	18	56	211	77	0.228	13.4	0.68
3/31/01	12:42:32	35.5	18	56	212	75.1	0.229	13.4	0.28
3/31/01	12:42:33	35.5	18	56	213	78.1	0.231	13.4	0.93
3/31/01	12:42:35	35.5	18	56	214	74.3	0.231	13.5	0.09
3/31/01	12:42:36	35.5	18	56	215	73.6	0.232	13.7	-0.56
3/31/01	12:42:38	35.5	18	56	216	75.5	0.232	13.5	0.52
3/31/01	12:42:39	35.5	18	56	217	72.4	0.229	13.3	-0.29
3/31/01	12:42:40	35.5	18	56	218	74	0.23	13.6	-0.33
3/31/01	12:42:42	35.5	18	56	219	75.8	0.23	13.5	0.14
3/31/01	12:42:43	35.5	18	56	220	75.6	0.232	13.6	0.21
3/31/01	12:42:45	35.5	18	56	221	73.2	0.227	13.4	-0.04
3/31/01	12:42:46	35.5	18	56	222	75.6	0.231	13.3	0.56
3/31/01	12:42:47	35.5	18	56	223	72	0.232	13.4	-0.34
3/31/01	12:42:49	35.5	18	56	224	70.9	0.22	13.2	-0.24
3/31/01	12:42:50	35.5	18	56	225	75.9	0.234	13.7	0.07
3/31/01	12:42:52	35.5	18	56	226	73.5	0.228	13.2	0.05
3/31/01	12:42:53	35.5	18	56	227	70.7	0.222	13.1	-0.26
3/31/01	12:42:54	35.5	18	56	228	72	0.226	13.3	-0.09
3/31/01	12:42:56	35.5	18	56	229	72	0.223	13.2	-0.23
3/31/01	12:42:57	35.5	18	56	230	73.4	0.223	13.3	-0.15
3/31/01	12:42:59	35.5	18	56	231	74.4	0.228	13.5	-0.01
3/31/01	12:43:00	35.5	18	56	232	71.9	0.222	13.2	0.01
3/31/01	12:43:01	35.5	18	56	233	70.1	0.221	13.2	-0.15
3/31/01	12:43:03	35.5	18	56	234	75.3	0.23	13.5	0.2
3/31/01	12:43:04	35.5	18	56	235	73.9	0.226	13.2	0.25

3/31/01	12:43:06	35.5	18	56	236	70.9	0.232	13.5	-0.49
3/31/01	12:43:07	35.5	18	56	237	70.8	0.224	13.3	-0.18
3/31/01	12.43:09	35.5	18	56	238	78	0.24	13.8	0.43
3/31/01	12:43:10	35.5	18	56	239	70.7	0.229	13.3	-0.45
3/31/01	14:21:46	39	12	20	14	75	0.259	14	-0.18
3/31/01	14:21:48	39.5	12	20	15	71.1	0.243	13.6	-0.07
3/31/01	14:21:49	39.5	12	20	16	72.8	0.25	13.8	0.02
3/31/01	14:21:51	39.5	12	20	17	72.4	0.251	13.8	-0.26
3/31/01	14:21:52	39.5	12	20	18	72	0.25	13.6	0.21
3/31/01	14:21:54	39.5	12	20	19	70.5	0.249	13.4	-0.41
3/31/01	14:21:55	39.5	12	20	20	70.2	0.251	13.7	-0.28
3/31/01	14:21:57	39.5	12	20	21	69	0.248	13.5	-0.44
3/31/01	14:21:58	39.5	12	20	22	68.8	0.249	13.6	-0.31
3/31/01	14:22:00	39.5	12	20	23	70.3	0.249	13.5	0.15
3/31/01	14:22:01	39.5	18	20	24	75.6	0.256	13.7	0.31
3/31/01	14:22:03	40	18	20	25	74.1	0.257	14	0.05
3/31/01	14:22:05	40	18	20	26	72	0.251	13.7	-0.01
3/31/01	14:22:06	40	18	20	27	74	0.263	14	-0.44
3/31/01	14:22:08	40	18	20	28	76.4	0.255	13.7	0.57
3/31/01	14:22:09	40	18	20	29	73.8	0.254	13.6	-0.11
3/31/01	14:22:11	40	18	20	30	77.7	0.264	14.1	0.44
3/31/01	14:22:13	40	18	20	31	71.9	0.249	13.3	0.26
3/31/01	14:22:14	40	18	20	32	73.7	0.256	13.8	0.1
3/31/01	14:22:16	40	18	20	33	72	0.244	13.2	0.33
3/31/01	14:53:15	49.5	12	25-50/2"	44	82.2	0.262	14.2	0.76
3/31/01	14:53:17	50	12	25-50/2"	45	83.1	0.269	14.7	0.24
3/31/01	14:53:18	50	12	25-50/2"	46	82.9	0.27	15.1	0.04
3/31/01	14:53:20	50	12	25-50/2"	47	78.5	0.267	14.6	-0.39
3/31/01	14:53:21	50	12	25-50/2"	48	76.7	0.268	15	-1.18
3/31/01	14:53:23	50	12	25-50/2"	49	79.3	0.277	15.2	-0.72
3/31/01	14:53:24	50	12	25-50/2"	50	75.2	0.272	15.1	-1.51
3/31/01	14:53:26	50	12	25-50/2"	51	78.2	0.264	14.7	-0.59
3/31/01	14:53:27	50	12	25-50/2"	52	79.2	0.259	14.5	-0.48
3/31/01	14:53:29	50	12	25-50/2"	53	85.6	0.261	14.4	0.24
3/31/01	14:53:30	50	12	25-50/2"	54	89.5	0.269	14.4	0.66
3/31/01	14:53:32	50	12	25-50/2"	55	86.4	0.264	14.4	0.06
3/31/01	14:53:33	50	12	25-50/2"	56	91.9	0.268	14.4	0.78
3/31/01	14:53:35	50	12	25-50/2"	57	93.3	0.268	14.4	1.13
3/31/01	14:53:36	50	12	25-50/2"	58	83	0.262	14.2	-0.9
3/31/01	14:53:38	50	12	25-50/2"	59	93	0.267	14.2	0.86
3/31/01	14:53:39	50	12	25-50/2"	60	87.5	0.27	14.5	-0.41
3/31/01	14:53:41	50	12	25-50/2"	61	88.6	0.266	14.5	-0.31
3/31/01	14:53:42	50	12	25-50/2"	62	90.7	0.269	14.5	0.05
3/31/01	14:53:44	50	12	25-50/2"	63	88.7	0.267	14.4	-0.14
3/31/01	14:53:45	50	12	25-50/2"	64	89.9	0.27	14.7	-0.09
3/31/01	14:53:47	50	12	25-50/2"	65	87.7	0.271	14.6	-0.42

3/31/01	14:53:48	50	12	25-50/2"	66	92.9	0.274	14.9	-0.32
3/31/01	14:53:50	50	12	25-50/2"	67	91.9	0.27	14.6	-0.13
3/31/01	14:53:52	50	12	25-50/2"	68	90.4	0.27	14.8	-0.37
3/31/01	14:53:53	50.5	14	25-50/2"	69	93.9	0.276	14.9	0.37
3/31/01	14:53:55	50.5	14	25-50/2"	70	84.9	0.269	14.6	-1.11
3/31/01	14:53:56	50.5	14	25-50/2"	71	88.9	0.257	14.4	-0.29
3/31/01	14:53:59	50.5	14	25-50/2"	73	82.9	0.257	14.4	-0.24
3/31/01	14:54:01	50.5	14	25-50/2"	74	89.2	0.265	14.5	0.79
3/31/01	14:54:02	50.5	14	25-50/2"	75	78.9	0.276	15	-1.26
3/31/01	14:54:03	50.5	14	25-50/2"	76	74.5	0.266	14.9	-1.17
3/31/01	14:54:05	50.5	14	25-50/2"	77	77.6	0.273	15	-1.18
3/31/01	14:54:08	50.5	14	25-50/2"	79	80.1	0.256	14.6	-0.76
3/31/01	14:54:09	50.5	14	25-50/2"	80	83.3	0.26	14.9	-0.43
3/31/01	14:54:11	50.5	14	25-50/2"	81	74.4	0.251	13.7	-0.26
3/31/01	14:54:12	50.5	14	25-50/2"	82	68.7	0.251	13.6	-1.36
3/31/01	14:54:14	50.5	14	25-50/2"	83	72.6	0.249	13.2	-0.48
3/31/01	14:54:15	50.5	14	25-50/2"	84	76.2	0.256	13.4	-0.16
3/31/01	14:54:17	50.5	14	25-50/2"	85	72.1	0.252	13.2	-0.65
3/31/01	14:54:18	50.5	14	25-50/2"	86	71	0.263	13.7	-1.45
3/31/01	14:54:20	50.5	14	25-50/2"	87	72.1	0.255	13.8	-0.81
3/31/01	14:54:21	50.5	14	25-50/2"	88	72.5	0.253	13.7	-0.89
3/31/01	14:54:23	50.5	14	25-50/2"	89	69.1	0.256	13.8	-1.57
3/31/01	14:54:24	50.5	14	25-50/2"	90	75.5	0.257	13.7	-0.35
3/31/01	14:54:26	50.5	14	25-50/2"	91	72.1	0.247	13.8	-0.55
3/31/01	14:54.27	50.5	14	25-50/2"	92	78.4	0.254	13.5	0.3
3/31/01	14:54:29	50.5	14	25-50/2"	93	72.4	0.258	13.6	-0.78
3/31/01	14:54:30	50.5	14	25-50/2"	94	74.7	0.258	13.7	-0.44
3/31/01	14:54:31	50.5	14	25-50/2"	95	75.2	0.257	13.8	-0.4
3/31/01	14:54:33	50.5	14	25-50/2"	96	75.8	0.259	13.9	-0.4
3/31/01	14:54:34	50.5	14	25-50/2"	97	71.2	0.242	13.5	-0.52
3/31/01	14:54:36	50.5	14	25-50/2"	98	72.4	0.247	13.4	-0.25
3/31/01	14:54:37	50.5	14	25-50/2"	99	71.8	0.247	13.5	-0.3
3/31/01	14:54:39	50.5	14	25-50/2"	100	82.1	0.259	14.9	-0.61
3/31/01	14:54:40	50.5	14	25-50/2"	101	67.1	0.238	13.3	-0.68
3/31/01	14:54:42	50.5	14	25-50/2"	102	66.3	0.243	13.3	-1.05
3/31/01	14:54:43	50.5	14	25-50/2"	103	71.1	0.238	13.5	-0.11
3/31/01	14:54:44	50.5	14	25-50/2"	104	86.9	0.241	14	1.02
3/31/01	14:54:46	50.5	14	25-50/2"	105	84.1	0.247	14.1	0.01
3/31/01	14:54:47	50.5	14	25-50/2"	106	80.9	0.249	14.1	-0.08
3/31/01	14:54:49	50.5	14	25-50/2"	107	74.1	0.251	13.6	-0.34
3/31/01	14:54:50	50.5	14	25-50/2"	108	75.3	0.255	14	-0.29
3/31/01	14:54:52	50.5	14	25-50/2"	109	71.6	0.25	13.4	-0.69
3/31/01	14:54:53	50.5	14	25-50/2"	110	74.1	0.257	14	-0.53
3/31/01	14:54:55	50.5	14	25-50/2"	111	70	0.25	13.2	-0.84
3/31/01	14:54:56	50.5	14	25-50/2"	112	70.3	0.247	13.3	-0.59
3/31/01	14:54:57	50.5	14	25-50/2"	113	71	0.255	13.5	-0.83

3/31/01	14:54:59	50.5	14	25-50/2"	114	69.1	0.251	13.8	-1.2
3/31/01	14:55:00	50.5	14	25-50/2"	115	73.1	0.256	13.8	-0.76
3/31/01	14:55:02	50.5	14	25-50/2"	116	69.9	0.248	13.7	-0.97
3/31/01	14:55:03	50.5	14	25-50/2"	117	72	0.254	14.1	-0.92
3/31/01	14:55:05	50.5	14	25-50/2"	118	70.5	0.252	13.7	-0.95
4/1/01	7:44:51	59.5	12	34-50/3"	12	64.8	0.201	11.6	0.75
4/1/01	7:44:52	59.5	12	34-50/3"	13	52.3	0.169	10.7	0.32
4/1/01	7:44:54	59.5	12	34-50/3"	14	51.5	0.168	10.9	0.35
4/1/01	7:44:55	59.5	12	34-50/3"	15	57.4	0.19	11.4	0.15
4/1/01	7:44:57	59.5	12	34-50/3"	16	54.3	0.177	11	0.17
4/1/01	7:44:58	59.5	12	34-50/3"	17	60	0.198	11.4	0.1
4/1/01	7:45:00	59.5	12	34-50/3"	18	54.6	0.179	11	0.1
4/1/01	7:45:01	59.5	12	34-50/3"	19	59.2	0.195	11.6	0.01
4/1/01	7:45:03	59.5	12	34-50/3"	20	57.9	0.188	11.1	0.1
4/1/01	7:45:04	59.5	12	34-50/3"	21	56	0.184	11	0.07
4/1/01	7:45:05	59.5	12	34-50/3"	22	52.5	0.171	10.6	0.07
4/1/01	7:45:07	59.5	12	34-50/3"	23	63	0.197	11.2	0.57
4/1/01	7:45:08	59.5	12	34-50/3"	24	60.6	0.193	11.2	0.33
4/1/01	7:45:10	59.5	12	34-50/3"	25	70.7	0.206	12.8	0.2
4/1/01	7:45:11	59.5	12	34-50/3"	26	68	0.202	12.7	0.07
4/1/01	7:45:12	59.5	12	34-50/3"	27	68.5	0.206	12.8	0.1
4/1/01	7:45:14	59.5	12	34-50/3"	28	60.6	0.199	11.7	-0.29
4/1/01	7:45:15	59.5	12	34-50/3"	29	56.8	0.195	11.6	-0.57
4/1/01	7:45:16	59.5	12	34-50/3"	30	65.9	0.199	12.8	-0.05
4/1/01	7:45:18	59.5	12	.34-50/3"	31	54.7	0.186	11.4	-0.44
4/1/01	7:45:19	59.5	12	34-50/3"	32	57.5	0.193	11.4	-0.24
4/1/01	7:45:21	59.5	12	34-50/3"	33	58.1	0.19	11.3	-0.11
4/1/01	7:45:22	59.5	12	34-50/3"	34	59.1	0.19	11.4	-0.07
4/1/01	7:45:24	59.5	12	34-50/3"	35	59.4	0.192	11.8	-0.18
4/1/01	7:45:25	59.5	12	34-50/3"	36	57.3	0.185	11.5	-0.12
4/1/01	7:45:26	59.5	12	34-50/3"	37	59.1	0.192	11.8	-0.17
4/1/01	7:45:28	59.5	12	34-50/3"	38	55.4	0.178	11.2	-0.1
4/1/01	7:45:29	59.5	12	34-50/3"	39	52.3	0.168	11	-0.08
4/1/01	7:45:30	59.5	12	34-50/3"	40	55.8	0.181	11.2	-0.21
4/1/01	7:45:32	59.5	12	34-50/3"	41	55.4	0.183	11.3	-0.21
4/1/01	7:45:33	59.5	12	34-50/3"	42	56	0.185	11.3	-0.24
4/1/01	7:45:35	59.5	12	34-50/3"	43	57	0.188	11.5	-0.21
4/1/01	7:45:36	59.5	12	34-50/3"	44	58.6	0.19	11.5	-0.11
4/1/01	7:45:37	59.5	12	34-50/3"	45	56.2	0.184	11.4	-0.15
4/1/01	7:45:39	59.5	15	34-50/3"	46	58.6	0.19	11.6	-0.12
4/1/01	7:45:40	60	15	34-50/3"	47	55.8	0.181	11.3	-0.1
4/1/01	7:45:42	60	15	34-50/3"	48	51.5	0.165	10.8	-0.05
4/1/01	7:45:43	60	15	34-50/3"	49	58.5	0.192	11.7	-0.25
4/1/01	7:45:44	60	15	34-50/3"	50	54.3	0.175	11	-0.04
4/1/01	7:45:46	60	15	34-50/3"	51	59.2	0.193	11.7	-0.15
4/1/01	7:45:47	60	15	34-50/3"	52	59.4	0.193	11.6	-0.06

4/1/01	7:45:48	60	15	34-50/3"	53	58.1	0.19	11.5	-0.13
4/1/01	7:45:50	60	15	34-50/3"	54	59.7	0.195	11.6	-0.1
4/1/01	7:45:51	60	15	34-50/3"	55	57.3	0.187	11.6	-0.13
4/1/01	7:45:53	60	15	34-50/3"	56	61.8	0.201	11.8	-0.02
4/1/01	7:45:54	60	15	34-50/3"	57	60.2	0.197	11.6	-0.1
4/1/01	7:45:55	60	15	34-50/3"	58	60.4	0.194	11.6	0.08
4/1/01	7:45:57	60	15	34-50/3"	59	59.8	0.192	11.5	0.15
4/1/01	7:45:58	60	15	34-50/3"	60	67.6	0.213	12.1	0.31
4/1/01	7:46:00	60	15	34-50/3"	61	65.1	0.207	12	0.19
4/1/01	7:46:01	60	15	34-50/3"	62	59.9	0.19	11.5	0.13
4/1/01	7:46:02	60	15	34-50/3"	63	64	0.206	11.9	-0.02
4/1/01	7:46:04	60	15	34-50/3"	64	64.4	0.207	12	0.05
4/1/01	7:46:05	60	15	34-50/3"	65	63.5	0.206	11.9	-0.05
4/1/01	7:46:07	60	15	34-50/3"	66	62.9	0.205	12	-0.08
4/1/01	7:46:08	60	15	34-50/3"	67	61.5	0.2	11.9	-0.07
4/1/01	7:46:09	60	15	34-50/3"	68	60	0.196	11.8	-0.05
4/1/01	7:46:11	60	15	34-50/3"	69	60.6	0.199	11.8	-0.08
4/1/01	7:46:12	60	15	34-50/3"	70	61.3	0.2	11.9	-0.11
4/1/01	7:46:13	60	15	34-50/3"	71	60.3	0.196	11.7	-0.04
4/1/01	7:46:15	60	15	34-50/3"	72	64.7	0.209	12.3	-0.02
4/1/01	7:46:16	60	15	34-50/3"	73	62.1	0.204	12	0.01
4/1/01	7:46:18	60	15	34-50/3"	74	62.2	0.199	11.9	0.05
4/1/01	7:46:19	60	15	34-50/3"	75	62	0.204	12	-0.01
4/1/01	7:46:21	60	15	34-50/3"	76	63.6	0.202	12.1	0.15
4/1/01	7:46:22	60	15	34-50/3"	77	63.6	0.207	12.2	0.04
4/1/01	7:46:23	60	15	34-50/3"	78	58	0.189	11.7	-0.04
4/1/01	7:46:25	60	15	34-50/3"	79	60.3	0.195	11.8	-0.15
4/1/01	7:46:26	60	15	34-50/3"	80	59	0.19	11.7	-0.07
4/1/01	7:46:28	60	15	34-50/3"	81	56	0.181	11.4	0
4/1/01	7:46:29	60	15	34-50/3"	82	60.4	0.196	11.8	-0.16
4/1/01	7:46:30	60	15	34-50/3"	83	60.4	0.197	11.9	-0.08
4/1/01	7:46:32	60	15	34-50/3"	84	59.6	0.196	11.8	-0.16
4/1/01	7:46:33	60	15	34-50/3"	85	58.7	0.192	11.8	-0.1
4/1/01	7:46:35	60	15	34-50/3"	86	60.2	0.195	11.7	-0.05
4/1/01	7:46:36	60	15	34-50/3"	87	59	0.193	11.9	-0.09
4/1/01	7:46:37	60	15	34-50/3"	88	57.9	0.189	11.6	-0.2
4/1/01	7:46:39	60	15	34-50/3"	89	57.7	0.188	11.7	-0.01
4/1/01	7:46:40	60	15	34-50/3"	90	58.2	0.19	11.7	-0.23
4/1/01	7:46:42	60	15	34-50/3"	91	58.3	0.19	11.8	-0.12
4/1/01	7:46:43	60	15	34-50/3"	92	62.4	0.208	12.1	-0.3
4/1/01	7:46:44	60	15	34-50/3"	93	58.8	0.194	12	-0.23
4/1/01	7:46:46	60	15	34-50/3"	94	59.5	0.195	12	-0.19
4/1/01	7:46:47	60	15	34-50/3"	95	56.2	0.185	11.7	-0.29
4/1/01	8:12:46	65	12	62	1216	0.3	0.198	11.3	0.12
4/1/01	8:12:47	65	12	62	122	58.8	0.197	11.2	0.04
4/1/01	8:12:49	65	12	62	123	60.5	0.198	11.3	0.15

4/1/01	8:12:50	65	12	62	124	60.8	0.203	11.4	-0.02
4/1/01	8:12:51	65	12	62	125	61.2	0.204	11.2	-0.03
4/1/01	8:12:53	65	12	62	126	60.6	0.202	11.4	0.03
4/1/01	8:12:54	65	12	62	127	61.2	0.205	11.5	-0.08
4/1/01	8:12:55	65	12	62	128	60.7	0.203	11.4	0.06
4/1/01	8:12:57	65	12	62	129	60.5	0.199	11.5	0.04
4/1/01	8:12:58	65	12	62	130	60.8	0.205	11.7	-0.07
4/1/01	8:12:59	65	12	62	131	60.2	0.2	11.7	0.01
4/1/01	8:13:01	65	12	62	132	59.5	0.202	11.5	-0.11
4/1/01	8:13:02	65	12	62	133	61.8	0.204	11.6	0.06
4/1/01	8:13:03	65	12	62	134	62.3	0.212	11.8	-0.14
4/1/01	8:13:05	65	12	62	135	61.8	0.203	11.6	0.04
4/1/01	8:13:06	65	12	62	136	61.3	0.209	11.6	-0.2
4/1/01	8:13:07	65	12	62	137	62.8	0.208	11.6	-0.08
4/1/01	8:13:09	65	12	62	138	61.4	0.209	11.7	-0.16
4/1/01	8:13:10	65	12	62	139	62.1	0.203	11.7	0
4/1/01	8:13:12	65	12	62	140	62.1	0.209	11.8	-0.11
4/1/01	8:13:13	65	12	62	141	62.3	0.208	11.9	-0.14
4/1/01	8:13:14	65	12	62	142	63.8	0.218	12.1	-0.29
4/1/01	8:13:16	65	12	62	143	62.6	0.209	11.5	-0.16
4/1/01	8:13:17	65	12	62	144	63	0.213	12	-0.2
4/1/01	8:13:18	65	12	62	145	58.6	0.196	11.5	-0.22
4/1/01	8:13:20	65	12	62	146	58	0.196	11.5	-0.26
4/1/01	8:13:21	65	12	62	14758.2		0.197	11.5	-0.29
4/1/01	8:13:22	65	12	62	148	59.1	0.201	11.7	-0.25
4/1/01	8:13:24	65	12	62	149	59.7	0.201	11.7	-0.25
4/1/01	8:13:25	65.5	12	62	150	62.3	0.212	12.1	-0.2
4/1/01	8:13:26	65.5	18	62	151	57.7	0.196	11.2	-0.24
4/1/01	8:13:28	65.5	18	62	152	59.9	0.207	11.5	-0.24
4/1/01	8:13:29	65.5	18	62	153	61.4	0.203	11.7	-0.07
4/1/01	8:13:30	65.5	18	62	154	60.6	0.205	11.7	-0.21
4/1/01	8:13:32	65.5	18	62	155	61.6	0.211	12	-0.25
4/1/01	8:13:33	65.5	18	62	156	62.1	0.212	11.8	-0.18
4/1/01	8:13:34	65.5	18	62	157	60.4	0.205	11.9	-0.24
4/1/01	8:13:36	65.5	18	62	158	61.1	0.211	11.8	-0.23
4/1/01	8:13:37	65.5	18	62	159	56.2	0.193	11.3	-0.32
4/1/01	8:13:38	65.5	18	62	160	61.1	0.207	11.9	-0.13
4/1/01	8:13:40	65.5	18	62	161	60.9	0.209	11.8	-0.29
4/1/01	8:13:41	65.5	18	62	162	61.7	0.21	11.8	-0.19
4/1/01	8:13:42	65.5	18	62	163	60.9	0.208	11.8	-0.24
4/1/01	8:13:44	65.5	18	62	164	62.2	0.213	12.1	-0.28
4/1/01	8:13:45	65.5	18	62	165	62.5	0.209	11.9	-0.17
4/1/01	8:13:47	65.5	18	62	166	62.2	0.211	12	-0.29
4/1/01	8:13:48	65.5	18	62	167	61.4	0.206	11.9	-0.3
4/1/01	8:13:49	65.5	18	62	168	62.1	0.213	12.1	-0.4
4/1/01	8:13:50	65.5	18	62	169	61	0.206	11.9	-0.42

4/1/01	8:13:52	65.5	18	62	170	61.5	0.212	12.1	-0.5
4/1/01	8:13:53	65.5	18	62	171	58.5	0.197	11.8	-0.36
4/1/01	8:13:55	65.5	18	62	172	61.4	0.208	12.2	-0.37
4/1/01	8:13:56	65.5	18	62	173	58.6	0.198	11.8	-0.41
4/1/01	8:13:57	65.5	18	62	174	61.8	0.213	12.2	-0.48
4/1/01	8:14:03	65.5	18	62	175	57.5	0.194	11.5	-0.52
4/1/01	8:14:04	65.5	18	62	176	60.1	0.201	11.9	-0.37
4/1/01	8:14:05	65.5	18	62	177	60.7	0.201	11.9	-0.38
4/1/01	8:14:07	65.5	18	62	178	59.7	0.203	11.8	-0.5
4/1/01	8:14:08	65.5	18	62	179	59	0.199	11.6	-0.47
4/1/01	8:14:09	65.5	18	62	180	60.3	0.206	11.9	-0.44
4/1/01	8.14:11	65.5	18	62	181	58.6	0.197	11.6	-0.54
4/1/01	8:14:12	65.5	18	62	182	59.7	0.204	11.8	-0.54
4/1/01	8:56:38	74.5	2	50/2"	183	74.3	0.23	13.2	-0.25
4/1/01	8:56:39	74.5	2	50/2"	184	70.2	0.208	13.1	-0.59
4/1/01	8:56:40	74.5	2	50/2"	185	70.4	0.202	13	-0.37
4/1/01	8:56:41	74.5	2	50/2"	186	72.1	0.211	13.2	-0.47
4/1/01	8:56:42	74.5	2	50/2"	187	70.6	0.202	13.1	-0.75
4/1/01	8:56:44	74.5	2	50/2"	188	72.6	0.208	13.2	-0.72
4/1/01	8:56:45	74.5	2	50/2"	189	71.5	0.201	13.2	-0.04
4/1/01	8:56:46	74.5	2	50/2"	190	72.4	0.208	13.2	-0.66
4/1/01	8:56:47	74.5	2	50/2"	191	69.5	0.199	13.1	-0.35
4/1/01	8:56:48	74.5	2	50/2"	192	71.7	0.208	13.1	-0.66
4/1/01	8:56:50	74.5	2	50/2"	193	69.1	0.197	13.1	-0.58
4/1/01	8:56:51	74.5	2	50/2"	194	69.9	0.201	13	-0.55
4/1/01	8:56:52	74.5	2	50/2"	195	69.3	0.195	12.9	-0.48
4/1/01	8:56:53	74.5	2	50/2"	196	70.3	0.201	13	-0.37
4/1/01	8:56:54	74.5	2	50/2"	197	70	0.2	13.3	-0.58
4/1/01	8:56:56	74.5	2	50/2"	198	70.6	0.205	13.3	-0.53
4/1/01	8.56:57	74.5	2	50/2"	199	70.1	0.201	13.3	-0.58
4/1/01	8:56:58	74.5	2	50/2"	200	71.5	0.206	13.3	-0.43
4/1/01	8:56:59	74.5	2	50/2"	201	73.4	0.207	13.4	-0.32
4/1/01	8:57:00	74.5	2	50/2"	202	74.3	0.212	13.2	-0.4
4/1/01	8:57:02	74.5	2	50/2"	203	72.2	0.204	13.3	-0.39
4/1/01	8:57:03	74.5	2	50/2"	204	72.1	0.206	13.3	-0.19
4/1/01	8:57:04	74.5	2	50/2"	205	70	0.197	13	-0.3
4/1/01	8:57:05	74.5	2	50/2"	206	70.9	0.204	13	-0.26
4/1/01	8:57:07	74.5	2	50/2"	207	69.6	0.195	13	0
4/1/01	8:57:08	74.5	2	50/2"	208	71.8	0.205	13.3	-0.07
4/1/01	8:57:09	74.5	2	50/2"	209	69.2	0.193	12.9	-0.03
4/1/01	8:57:10	74.5	2	50/2"	210	71.6	0.202	13.2	-0.04
4/1/01	8:57:12	74.5	2	50/2"	211	71.9	0.201	13.3	0
4/1/01	8:57:13	74.5	2	50/2"	212	72	0.203	13.3	0.12
4/1/01	8:57:14	74.5	2	50/2"	213	71.8	0.199	13.3	0.07
4/1/01	8:57:15	74.5	2	50/2"	214	70	0.198	13	0.24
4/1/01	8:57:16	74.5	2	50/2"	215	70.7	0.197	13	0.13

4/1/01	8:57:18	74.5	2	50/2"	216	67.7	0.195	12.6	0.14
4/1/01	8:57:19	74.5	2	50/2"	217	68.5	0.194	13.2	0
4/1/01	8:57:20	74.5	2	50/2"	218	70.8	0.2	13.2	0.1
4/1/01	8:57:21	74.5	2	50/2"	219	66.8	0.19	12.9	0.02
4/1/01	8:57:23	74.5	2	50/2"	220	69.7	0.2	13.2	0.08
4/1/01	8:57:24	74.5	2	50/2"	221	71.2	0.199	13.4	0.13
4/1/01	8:57:25	74.5	2	50/2"	222	73.2	0.204	13.2	0.4
4/1/01	8:57:26	74.5	2	50/2"	223	67.6	0.187	12.5	0.2
4/1/01	8:57:27	74.5	2	50/2"	224	68.9	0.196	13.3	0.19
4/1/01	8:57:29	74.5	2	50/2"	225	68.4	0.19	12.7	0.19
4/1/01	8:57:30	74.5	2	50/2"	226	69.6	0.199	13	0.01
4/1/01	8:57:31	74.5	2	50/2"	227	63.8	0.194	12.3	-0.02
4/1/01	8:57:32	74.5	2	50/2"	228	62.3	0.203	12.3	-0.5
4/1/01	8:57:34	74.5	2	50/2"	229	60.3	0.203	12.5	-1.01
4/1/01	8:57:35	74.5	2	50/2"	230	66.1	0.208	12.5	-0.25
4/1/01	8:57:36	74.5	2	50/2"	231	66.3	0.19	12.8	-0.21
4/1/01	8:57:38	74.5	2	50/2"	232	72	0.204	13	0.22

Donut Hammer
Mobile B61

1.16	inches^2	Area
0.492083	kips/feet^3	Specific Weight Density
16807.7	feet/second	Wave Speed
29999.6	ksi	Elastic Modulus

Strain Gage Calibration Factors

F3	F1	219.73
F4	F2	218.87

Accelerometer Calibration Factors

A3	A1	400
A4	A2	415

PJ	MD 32
PN	B-4-2A
PD	COLS OF BRIDGE; DONUT; MOBILE B61
OP	LINWOOD

Depth	N	Average ETR	St dev of ETR
feet		(%)	
4	19	58.99	3.76
9	23	66.22	5.45
14	23	64.71	2.85
19	12	68.33	4.97
24	17	67.84	3.59
29	60	63.36	2.98
34	59	62.98	4.38
39	50/3"	63.15	2.88
	Total Ave	63.53	4.31

Donut Hammer
Mobile B61

1.16	inches^2	Area
9	feet	Length
0.492083	kips/ feet^3	Specific Weight Density
16807.7	feet/ second	Wave Speed
29999.6	ksi	Elastic Modulus

Strain Gage Calibration Factors

F3	F1	220
F4	F2	219

Accelerometer Calibration Factors

A3	A1	400
A4	A2	415

PJ	MD 32
PN	B-4-2A
PD	COLS OF BRIDGE; DONUT; MOBILE B61
OP	LINWOOD

Date	Time	LP feet	Penetration in	N	SL	ETR (%)	EF2 kip-feet	VMX feet/second	FMX kips	DFN inches
4/20/01	8:00:17	9.5	12	23	10	59.5	0.1	9.9	19	-0.12
4/20/01	8:00:19	9.5	12	23	11	66.6	0.2	10.4	21	0.39
4/20/01	8:00:20	9.5	12	23	12	64.4	0.1	10.7	20	0.14
4/20/01	8:00:21	9.5	12	23	13	64.2	0.2	11.5	22	0.29
4/20/01	8:00:23	9.5	12	23	14	60.6	0.1	10.6	21	0.29
4/20/01	8:00:24	9.5	12	23	15	67.3	0.2	12.6	24	0.77
4/20/01	8:00:25	9.5	12	23	16	62.8	0.1	10.9	19	0.81
4/20/01	8:00:27	9.5	12	23	17	68.6	0.2	11.4	23	0.74
4/20/01	8:00:28	10	12	23	18	62.5	0.1	11.2	19	1.18
4/20/01	8:00:30	10	12	23	19	57	0.1	11.8	20	1.4
4/20/01	8:00:31	10	12	23	20	64.2	0.1	11.3	20	1.49
4/20/01	8:00:32	10	12	23	21	56.1	0.1	12.1	19	1.48
4/20/01	8:00:33	10	18	23	22	69.8	0.2	12.9	24	1.71
4/20/01	8:00:35	10	18	23	23	64.4	0.2	13.2	25	1.7
4/20/01	8:00:36	10	18	23	24	62.8	0.1	11.1	20	1.28
4/20/01	8:00:45	10.5	18	23	25	76.5	0.2	13.3	25	1.81
4/20/01	8:00:47	10.5	18	23	26	71.7	0.2	11.8	23	1.44
4/20/01	8:00:48	10.5	18	23	27	64.6	0.1	11.1	20	1.2
4/20/01	8:00:49	10.5	18	23	28	75	0.2	13.3	25	1.79
4/20/01	8:00:50	10.5	18	23	29	68.3	0.2	12.3	23	1.25
4/20/01	8:00:52	10.5	18	23	30	73.6	0.2	12.8	25	1.55
4/20/01	8:00:53	10.5	18	23	31	72.5	0.2	12.4	23	1.45
4/20/01	8:00:55	10.5	18	23	32	71.7	0.2	12.7	25	1.52
4/20/01	8:15:48	15	12	23	76	2.2	0.2	11.3	22	1.19

Donut Hammer
Mobile B61

4/20/01	8:15:49	15	12	23	8	62.2	0.2	11.2	22	1.18
4/20/01	8:15:50	15	12	23	9	62.2	0.2	11.1	22	1.23
4/20/01	8:15:52	15	12	23	10	61.1	0.1	10.2	18	1.06
4/20/01	8:15:53	15	12	23	11	68.5	0.2	11.9	25	1.48
4/20/01	8:15:54	15	12	23	12	64	0.2	10.1	20	1.06
4/20/01	8:15:56	15	12	23	13	64.5	0.2	10.2	21	1.12
4/20/01	8:15:57	15	12	23	14	67.8	0.2	11	21	1.15
4/20/01	8:15:59	15	12	23	15	68.3	0.2	11.4	23	1.23
4/20/01	8:16:00	15.5	12	23	16	62.7	0.2	10.2	20	0.98
4/20/01	8:16:01	16	18	23	17	63.2	0.2	10.2	19	0.95
4/20/01	8:16:03	16	18	23	18	66	0.2	10.8	22	1.08
4/20/01	8:16:04	16	18	23	19	66.3	0.2	10.6	21	1.04
4/20/01	8:16:05	16	18	23	20	67.1	0.2	10.2	20	1.17
4/20/01	8:16:06	16	18	23	21	67.3	0.2	11.6	22	1.12
4/20/01	8:16:08	16	18	23	22	64.8	0.2	10.7	22	1.04
4/20/01	8:16:09	16	18	23	23	65.2	0.2	11.9	22	0.99
4/20/01	8:16:10	16	18	23	24	66.3	0.2	10.9	21	0.75
4/20/01	8:16:12	16	18	23	25	60.3	0.1	10.1	20	0.84
4/20/01	8:16:13	16	18	23	26	60.7	0.1	10	19	0.93
4/20/01	8:16:14	16	18	23	27	63.7	0.1	10.5	19	0.99
4/20/01	8:16:16	16	18	23	28	71.3	0.2	11.4	22	1.1
4/20/01	8:16:17	16	18	23	29	62.7	0.1	10.4	18	0.72
4/20/01	8:25:40	20	12	12	6	72.9	0.2	13.2	25	2.29
4/20/01	8:25:41	20	12	12	7	64.3	0.2	11.4	22	1.83
4/20/01	8:25:43	20	12	12	8	58.7	0.2	10.6	18	1.44
4/20/01	8:25:44	20	12	12	9	62.2	0.2	10.5	18	1.37
4/20/01	8:25:46	20	12	12	10	68.9	0.2	12.5	23	1.66
4/20/01	8:25:47	20.5	18	12	11	73.1	0.2	11.8	23	1.59
4/20/01	8:25:49	20.5	18	12	12	68	0.2	12.5	23	1.69
4/20/01	8:25:50	20.5	18	12	13	76.2	0.2	13	25	1.86
4/20/01	8:25:52	20.5	18	12	14	70.3	0.2	12.9	24	1.84
4/20/01	8:25:53	20.5	18	12	15	65.3	0.2	11.6	21	1.55
4/20/01	8:25:55	20.5	18	12	16	70	0.2	11.3	21	1.45
4/20/01	8:25:56	20.5	18	12	17	70.1	0.2	11.8	22	1.54
4/20/01	8:35:57	24	12	17	5	64.7	0.2	11.7	16	1.69
4/20/01	8:36:02	24.5	12	17	6	66.5	0.2	12.7	20	1.79
4/20/01	8:36:03	24.5	12	17	7	69.7	0.2	12.9	22	1.69
4/20/01	8:36:05	24.5	12	17	8	62.6	0.2	11.5	19	1.46
4/20/01	8:36:06	24.5	12	17	9	63.3	0.2	11.2	15	1.38
4/20/01	8:36:08	24.5	12	17	10	70.9	0.2	12.2	20	1.74
4/20/01	8:36:09	24.5	12	17	11	70.7	0.2	11.1	19	1.66
4/20/01	8:36:11	25	18	17	12	70	0.2	12	20	1.56
4/20/01	8:36:12	25	18	17	13	61.1	0.2	10.5	16	1.17
4/20/01	8:36:13	25	18	17	14	67.3	0.2	11.5	18	1.55
4/20/01	8:36:15	25	18	17	15	67.8	0.2	11.3	18	1.34
4/20/01	8:36:16	25	18	17	16	63.8	0.2	10.7	17	1.25

Donut Hammer
Mobile B61

4/20/01	8:36:17	25	18	17	17	69.9	0.2	12.1	20	1.38
4/20/01	8:36:19	25	18	17	18	70.5	0.2	11.8	19	1.16
4/20/01	8:36:20	25	18	17	19	73.6	0.2	12.1	20	1.55
4/20/01	8:36:22	25	18	17	20	70.8	0.2	11.8	19	1.6
4/20/01	8:36:23	25	18	17	21	70.1	0.2	11.8	19	1.45
4/20/01	8:48:11	30	12	60	10	71	0.2	11	16	1.28
4/20/01	8:48:13	30	12	60	11	64.6	0.2	11.7	17	1.05
4/20/01	8:48:14	30	12	60	12	69.7	0.2	12.3	21	1.23
4/20/01	8:48:16	30	12	60	13	64.3	0.2	12.7	21	0.73
4/20/01	8:48:17	30	12	60	14	61.1	0.2	10.5	16	0.82
4/20/01	8:48:19	30	12	60	15	61.3	0.2	10.1	16	0.78
4/20/01	8:48:20	30	12	60	16	64.9	0.2	11.7	18	0.77
4/20/01	8:48:21	30	12	60	17	61.3	0.2	11.6	17	0.81
4/20/01	8:48:23	30	12	60	18	65.6	0.2	12	18	0.87
4/20/01	8:48:24	30	12	60	19	64.2	0.2	11.9	17	0.83
4/20/01	8:48:25	30	12	60	20	63.8	0.2	11.5	17	0.72
4/20/01	8:48:27	30	12	60	21	60.3	0.2	12.2	18	0.74
4/20/01	8:48:28	30	12	60	22	62.3	0.2	11.2	16	0.76
4/20/01	8:48:29	30	12	60	23	62.3	0.2	11.5	17	0.84
4/20/01	8:48:31	30	12	60	24	60.3	0.2	11.2	18	0.59
4/20/01	8:48:32	30	12	60	25	65	0.2	12.8	22	0.91
4/20/01	8:48:33	30	12	60	26	66.7	0.2	12.9	22	0.84
4/20/01	8:48:34	30	12	60	27	65.6	0.2	11.2	16	0.86
4/20/01	8:48:36	30	12	60	28	68.1	0.2	12.9	22	0.78
4/20/01	8:48:37	30	12	60	29	61.9	0.2	10.8	15	0.54
4/20/01	8:48:38	30	12	60	30	69.3	0.2	13.3	22	0.74
4/20/01	8:48:40	30	12	60	31	59.9	0.2	10.4	17	0.45
4/20/01	8.48:41	30.5	12	60	32	70.8	0.2	13.9	23	0.86
4/20/01	8:48.42	30.5	12	60	33	61.9	0.1	11.3	15	0.74
4/20/01	8:48:44	30.5	18	60	34	60.1	0.2	11.1	16	0.47
4/20/01	8:48:45	30.5	18	60	35	60.9	0.2	11.7	16	0.56
4/20/01	8:48:46	30.5	18	60	36	61.2	0.2	11.3	16	0.48
4/20/01	8:48:47	30.5	18	60	37	60.3	0.2	11	16	0.53
4/20/01	8:48:49	30.5	18	60	38	67.3	0.2	13.6	22	0.64
4/20/01	8:48:50	30.5	18	60	39	65	0.2	12.6	19	0.61
4/20/01	8:48:51	30.5	18	60	40	61	0.2	11.7	18	0.57
4/20/01	8:48:53	30.5	18	60	41	61.1	0.2	11.3	16	0.53
4/20/01	8:48:54	30.5	18	60	42	61.1	0.2	10.6	16	0.43
4/20/01	8:48:55	30.5	18	60	43	66.2	0.2	14.4	23	0.66
4/20/01	8:48:56	30.5	18	60	44	63.9	0.2	12.3	17	0.5
4/20/01	8:48:57	30.5	18	60	45	59.4	0.2	11.4	16	0.5
4/20/01	8:48:59	30.5	18	60	46	64.1	0.2	12.4	18	0.53
4/20/01	8:49:00	30.5	18	60	47	61	0.2	12.3	18	0.55
4/20/01	8:49:01	30.5	18	60	48	63.7	0.2	12	18	0.55
4/20/01	8:49:02	30.5	18	60	49	59.7	0.2	12.2	18	0.45
4/20/01	8:49:04	30.5	18	60	50	64.2	0.2	12.9	19	0.47

Donut Hammer
Mobile B61

4/20/01	8:49:05	30.5	18	60	51	61.2	0.2	12.3	18	0.5
4/20/01	8:49:06	30.5	18	60	52	59.4	0.2	12	18	0.3
4/20/01	8:49:07	30.5	18	60	53	62.4	0.2	12.6	18	0.62
4/20/01	8:49:09	30.5	18	60	.54	58.7	0,2	10.3	17	0.34
4/20/01	8:49:10	30.5	18	60	55	63.7	0.2	13.9	21	0.48
4/20/01	8:49:11	30.5	18	60	56	63.8	0.2	12.6	18	0.55
4/20/01	8:49:12	30.5	18	60	57	60.7	0.2	12.5	18	0.54
4/20/01	8:49:14	30.5	18	60	58	65.4	0.2	13.1	20	0.5
4/20/01	8:49:15	30.5	18	60	59	58.1	0.2	10.4	16	0.4
4/20/01	8:49:16	30.5	18	60	60	62.7	0.2	12.6	19	0.47
4/20/01	8:49:18	30.5	18	60	61	62	0.2	13	19	0.54
4/20/01	8:49:19	30.5	18	60	62	64.5	0.2	13.9	22	0.64
4/20/01	8:49:20	30.5	18	60	63	64.9	0.2	13.7	21	0.55
4/20/01	8:49:21	30.5	18	60	64	64.5	0.2	13	19	0.53
4/20/01	8:49:23	30.5	18	60	65	61.1	0.2	13.4	20	0.49
4/20/01	8:49:24	30.5	18	60	66	65.7	0.2	13.8	21	0.45
4/20/01	8:49:25	30.5	18	60	67	64.9	0.2	13.4	20	0.4
4/20/01	8.49:27	30.5	18	60	68	67.7	0.2	13.5	20	0.46
4/20/01	8:49:28	30.5	18	60	69	63.8	0.2	13.5	20	0.47
4/20/01	9:00:10	35	12	59	17	63.9	0.2	10.5	16	0.72
4/20/01	9:00:11	35	12	59	18	68	0.2	12.6	18	0.61
4/20/01	9:00:13	35	12	59	19	65.8	0.2	11.7	16	0.6
4/20/01	9:00:14	35	12	59	20	60.5	0.2	10.4	15	0.56
4/20/01	9:00:15	35	12	59	21	61.3	0.2	10.4	16	0.55
4/20/01	9:00:17	35	12	59	22	64.8	0.2	10.6	16	0.64
4/20/01	9:00:18	35	12	59	23	65.4	0.2	11.3	16	0.64
4/20/01	9:00:19	35	12	59	24	64.6	0.2	11	15	0.56
4/20/01	9:00:21	35	12	59	25	66.1	0.2	10.7	16	0.41
4/20/01	9:00:22	35	12	59	26	75.2	0.2	14	21	0.6
4/20/01	9:00:24	35	12	59	27	67.8	0.2	11.4	16	0.59
4/20/01	9:00:25	35	12	59	28	76.6	0.2	13.6	20	1.02
4/20/01	9:00:26	35	12	59	29	64.1	0.2	10.2	17	0.48
4/20/01	9:00:28	35	12	59	30	64.4	0.2	10.8	15	0.48
4/20/01	9:00:29	35	12	59	31	69.8	0.2	12.2	17	0.73
4/20/01	9:00:31	35	12	59	32	66	0.2	11.8	17	0.58
4/20/01	9:00:32	35	12	59	33	69.2	0.2	12.1	17	0.7
4/20/01	9:00:33	35	12	59	34	67.4	0.2	13.1	18	0.57
4/20/01	9:00:35	35	12	59	35	67.7	0.2	12.5	18	0.46
4/20/01	9:00:36	35	12	59	36	66.6	0.2	13	18	0.53
4/20/01	9:00:38	35	12	59	37	61.8	0.2	12	15	0.47
4/20/01	9:00:39	35	12	59	38	64.1	0.2	11.8	15	0.44
4/20/01	9:00:45	35.5	18	59	39	69.6	0.2	13.7	16	0.37
4/20/01	9:00:46	35.5	18	59	40	64.5	0.2	11.8	16	0.55
4/20/01	9:00:48	35.5	18	59	41	67.3	0.2	11.3	17	0.55
4/20/01	9:00:49	35.5	18	59	42	70.6	0.2	13.2	19	0.63
4/20/01	9:00:50	35.5	18	59	43	62.3	0.2	9.8	15	0.4

Donut Hammer

Mobile B61

4/20/01	9:00:52	35.5	18	59	44	59.8	0.2	10.2	17	0.33
4/20/01	9:00:53	35.5	18	59	45	62.9	0.2	10.1	17	0.4
4/20/01	9:00:55	35.5	18	59	46	64.5	0.2	12.5	20	0.23
4/20/01	9:00:56	35.5	18	59	47	58.1	0.2	9	16	0.25
4/20/01	9:00:57	35.5	18	59	48	63.3	0.2	9.9	17	0.38
4/20/01	9:00:59	35.5	18	59	49	59.5	0.2	10.3	18	0.29
4/20/01	9:01:00	35.5	18	59	50	60.4	0.2	11.1	18	0.33
4/20/01	9:01:02	35.5	18	59	51	60	0.2	9.5	16	0.29
4/20/01	9:01:03	35.5	18	59	52	60.1	0.2	9.4	15	0.36
4/20/01	9:01:04	35.5	18	59	53	59.2	0.2	9.3	16	0.23
4/20/01	9:01:06	35.5	18	59	54	62.8	0.2	10.6	17	0.45
4/20/01	9:01:07	35.5	18	59	55	57.7	0.2	9.1	15	0.26
4/20/01	9:01:09	35.5	18	59	56	60.3	0.2	10.7	18	0.3
4/20/01	9:01:10	35.5	18	59	57	64.1	0.2	11.8	20	0.35
4/20/01	9:01:11	35.5	18	59	58	61	0.2	10.5	17	0.32
4/20/01	9:01:13	35.5	18	59	59	61.3	0.2	10.9	18	0.3
4/20/01	9:01:14	35.5	18	59	60	61.2	0.2	11.5	19	0.34
4/20/01	9:01:15	35.5	18	59	61	59.4	0.2	10	16	0.34
4/20/01	9:01:17	35.5	18	59	62	59.5	0.2	10.2	17	0.34
4/20/01	9:01:18	35.5	18	59	63	56.7	0.2	9.8	16	0.34
4/20/01	9:01:20	35.5	18	59	64	60.2	0.2	10.5	17	0.33
4/20/01	9:01:21	35.5	18	59	65	57.5	0.2	11.4	18	0.3
4/20/01	9:01:23	35.5	18	59	66	60.1	0.2	10.6	18	0.35
4/20/01	9:01:24	35.5	18	59	67	61.4	0.2	12.2	20	0.29
4/20/01	9:01:26	35.5	18	59	68	57.1	0.2	9.2	15	0.3
4/20/01	9:01:27	35.5	18	59	69	58.1	0.2	9.5	15	0.24
4/20/01	9:01:28	35.5	18	59	70	61.3	0.2	10.8	18	0.27
4/20/01	9:01:30	35.5	18	59	71	59.4	0.2	9.6	15	0.34
4/20/01	9:01:31	35.5	18	59	72	59.8	0.2	10.6	17	0.23
4/20/01	9:01:33	35.5	18	59	73	57.8	0.2	9.9	16	0.26
4/20/01	9:01:34	35.5	18	59	74	59.5	0.2	10.2	16	0.32
4/20/01	9:01:36	35.5	18	59	75	56.6	0.2	9.9	16	0.25
4/20/01	9:16:43	40	12	35-50/3"	13	61.6	0.2	13.4	19	0.66
4/20/01	9:16:45	40	12	35-50/3"	14	67.2	0.2	13.4	22	0.4
4/20/01	9:16:46	40	12	35-50/3"	15	61.9	0.2	12.3	16	0.51
4/20/01	9:16:47	40	12	35-50/3"	16	59.3	0.2	10.8	15	0.6
4/20/01	9:16:48	40	12	35-50/3"	17	61.8	0.2	12.2	17	0.66
4/20/01	9:16:49	40	12	35-50/3"	18	65.8	0.2	14	19	0.59
4/20/01	9:16:51	40	12	35-50/3"	19	64.5	0.2	12.8	21	0.54
4/20/01	9:16:52	40	12	35-50/3"	20	64.6	0.2	13.9	20	0.49
4/20/01	9:16:53	40	12	35-50/3"	21	57.4	0.2	12.3	16	0.45
4/20/01	9:16:54	40	12	35-50/3"	22	60.6	0.2	12.5	16	0.54
4/20/01	9:16:55	40	12	35-50/3"	23	61.9	0.2	14	18	0.49
4/20/01	9:16:57	40	12	35-50/3"	24	60.9	0.2	13.5	17	0.41
4/20/01	9:16:58	40	12	35-50/3"	25	56.8	0.2	10.9	17	0.36
4/20/01	9:16:59	40	12	35-50/3"	26	60.8	0.2	11.2	16	0.34

Donut Hammer
Mobile B61

4/20/01	9:17:00	40	12	35-50/3"	27	64.9	0.2	13.9	20	0.51
4/20/01	9:17:01	40	12	35-50/3"	28	66.1	0.2	13.8	22	0.36
4/20/01	9:17:02	40	12	35-50/3"	29	67.8	0.2	12.9	19	0.55
4/20/01	9:17:04	40	12	35-50/3"	30	69.4	0.2	13.2	21	0.65
4/20/01	9:17:05	40	12	35-50/3"	31	64.1	0.2	12.1	18	0.43
4/20/01	9:17:06	40	12	35-50/3"	32	62.3	0.2	13.4	17	0.24
4/20/01	9:17:07	40	12	35-50/3"	33	63.2	0.2	13.6	21	0.4
4/20/01	9:17:08	40	12	35-50/3"	34	61.8	0.2	11.5	16	0.52
4/20/01	9:17:10	40	12	35-50/3"	35	64.5	0.2	11.2	16	0.75
4/20/01	9:17:11	40	12	35-50/3"	36	61	0.2	12.3	16	0.38
4/20/01	9:17:12	40	12	35-50/3"	37	61.2	0.2	12.8	19	0.34
4/20/01	9:17:13	40	12	35-50/3"	38	66.9	0.2	13.7	22	0.44
4/20/01	9:17:14	40	12	35-50/3"	39	63.9	0.2	13.1	17	0.34
4/20/01	9:17:16	40	12	35-50/3"	40	65.3	0.2	13.4	17	0.38
4/20/01	9:17:17	40	12	35-50/3"	41	66.2	0.2	13.1	22	0.43
4/20/01	9:17:18	40	12	35-50/3"	42	65.4	0.2	13.6	22	0.33
4/20/01	9:17:19	40	12	35-50/3"	43	63.5	0.2	13.5	20	0.33
4/20/01	9:17:20	40	12	35-50/3"	44	69.5	0.2	14.1	20	0.37
4/20/01	9:17:22	40	12	35-50/3"	45	69	0.2	13.4	19	0.4
4/20/01	9:17:23	40	12	35-50/3"	46	67.3	0.2	14.3	19	0.39
4/20/01	9:17:24	40	12	35-50/3"	47	65.6	0.2	12.1	19	0.33
4/20/01	9:17:25	40.5	15	35-50/3"	48	67.6	0.2	14.5	22	0.37
4/20/01	9:17:26	40.5	15	35-50/3"	49	64	0.2	12.4	18	0.4
4/20/01	9:17:27	40.5	15	35-50/3"	50	62.5	0.2	13.6	19	0.27
4/20/01	9:17:29	40.5	15	35-50/3"	51	63	0.2	12	16	0.53
4/20/01	9:17:30	40.5	15	35-50/3"	52	59.7	0.2	11.6	16	0.37
4/20/01	9:17:31	40.5	15	35-50/3"	53	64.5	0.2	12	17	0.52
4/20/01	9:17:32	40.5	15	35-50/3"	54	64.5	0.2	12.2	17	0.62
4/20/01	9:17:33	40.5	15	35-50/3"	55	66.6	0.2	14.1	20	0.35
4/20/01	9:17:34	40.5	15	35-50/3"	56	63	0.2	13.8	18	0.35
4/20/01	9:17:35	40.5	15	35-50/3"	57	66.5	0.2	14.1	20	0.45
4/20/01	9:17:37	40.5	15	35-50/3"	58	61.1	0.2	12.5	17	0.37
4/20/01	9:17:38	40.5	15	35-50/3"	59	60.4	0.2	12.5	16	0.3
4/20/01	9:17:39	40.5	15	35-50/3"	60	59.3	0.2	12.9	17	0.27
4/20/01	9:17:40	40.5	15	35-50/3"	61	60.1	0.2	12.8	16	0.28
4/20/01	9:17:41	40.5	15	35-50/3"	62	59	0.2	13.4	18	0.18
4/20/01	9:17:42	40.5	15	35-50/3"	63	60.7	0.2	11.3	16	0.43
4/20/01	9:17:44	40.5	15	35-50/3"	64	62	0.2	13.2	21	0.2
4/20/01	9:17:45	40.5	15	35-50/3"	65	63.8	0.2	11.9	18	0.46
4/20/01	9:17:46	40.5	15	35-50/3"	66	59.4	0.2	10.6	16	0.26
4/20/01	9:17:47	40.5	15	35-50/3"	67	59.6	0.2	13	18	0.22
4/20/01	9:17:48	40.5	15	35-50/3"	68	62.2	0.2	13.8	19	0.18
4/20/01	9:17:49	40.5	15	35-50/3"	69	61.9	0.2	12.2	16	0.27
4/20/01	9:17:51	40.5	15	35-50/3"	70	64	0.2	13.1	19	0.52
4/20/01	9:17:52	40.5	15	35-50/3"	71	58.1	0.2	13	17	0.11
4/20/01	9:17:53	40.5	15	35-50/3"	72	62.1	0.2	12	17	0.29

Donut Hammer

Mobile B61

4/20/01	9:17:54	40.5	15	35-50/3"	73	61.4	0.2	13.3	17	0.17
4/20/01	9:17:55	40.5	15	35-50/3"	74	60.6	0.2	12.9	16	0.21
4/20/01	9:17:56	40.5	15	35-50/3"	75	60.9	0.2	13.7	20	0.17
4/20/01	9:17:58	40.5	15	35-50/3"	76	67.9	0.2	14.4	20	0.39
4/20/01	9:17:59	40.5	15	35-50/3"	77	63	0.2	11.6	18	0.43
4/20/01	9:18:00	40.5	15	35-50/3"	78	64.8	0.2	14	20	0.18
4/20/01	9:18:01	40.5	15	35-50/3"	79	62.8	0.2	13.4	18	0.28
4/20/01	9:18:03	40.5	15	35-50/3"	80	68.1	0.2	14	20	0.62
4/20/01	9:18:04	40.5	15	35-50/3"	81	64.7	0.2	12.6	21	0.27
4/20/01	9:18:05	40.5	15	35-50/3"	82	63.3	0.2	13.3	19	0.25
4/20/01	9:18:06	40.5	15	35-50/3"	83	61.3	0.2	13.2	18	0.27
4/20/01	9:18:07	40.5	15	35-50/3"	84	60.3	0.2	13.5	18	0.18
4/20/01	9:18:08	40.5	15	35-50/3"	85	63.1	0.2	12.5	19	0.64
4/20/01	9:18:10	40.5	15	35-50/3"	86	60.9	0.2	13	21	0.21
4/20/01	9:18:11	40.5	15	35-50/3"	87	63.6	0.2	11.2	18	0.56
4/20/01	9:18:12	40.5	15	35-50/3"	88	62.5	0.2	13.6	21	0.19
4/20/01	9:18:13	40.5	15	35-50/3"	89	59.7	0.2	13.3	18	0.17
4/20/01	9:18:14	40.5	15	35-50/3"	90	64.2	0.2	14	19	0.29
4/20/01	9:18:15	40.5	15	35-50/3"	91	63.3	0.2	13.8	21	0.3
4/20/01	9:18:17	40.5	15	35-50/3"	92	61.4	0.2	13	16	0.4
4/20/01	9:18:18	40.5	15	35-50/3"	93	65.3	0.2	12.5	19	0.68
4/20/01	9:18:19	40.5	15	35-50/3"	94	57.5	0.2	12.2	16	0.32

APPENDIX C

Photos From the Field Testing

Fig. 1 Instrumented Rod

Fig. 2 SPT Analyzer

Fig. 3 Mobile Drill Rig on Site

Fig. 4 Instrumented Safety Hammer

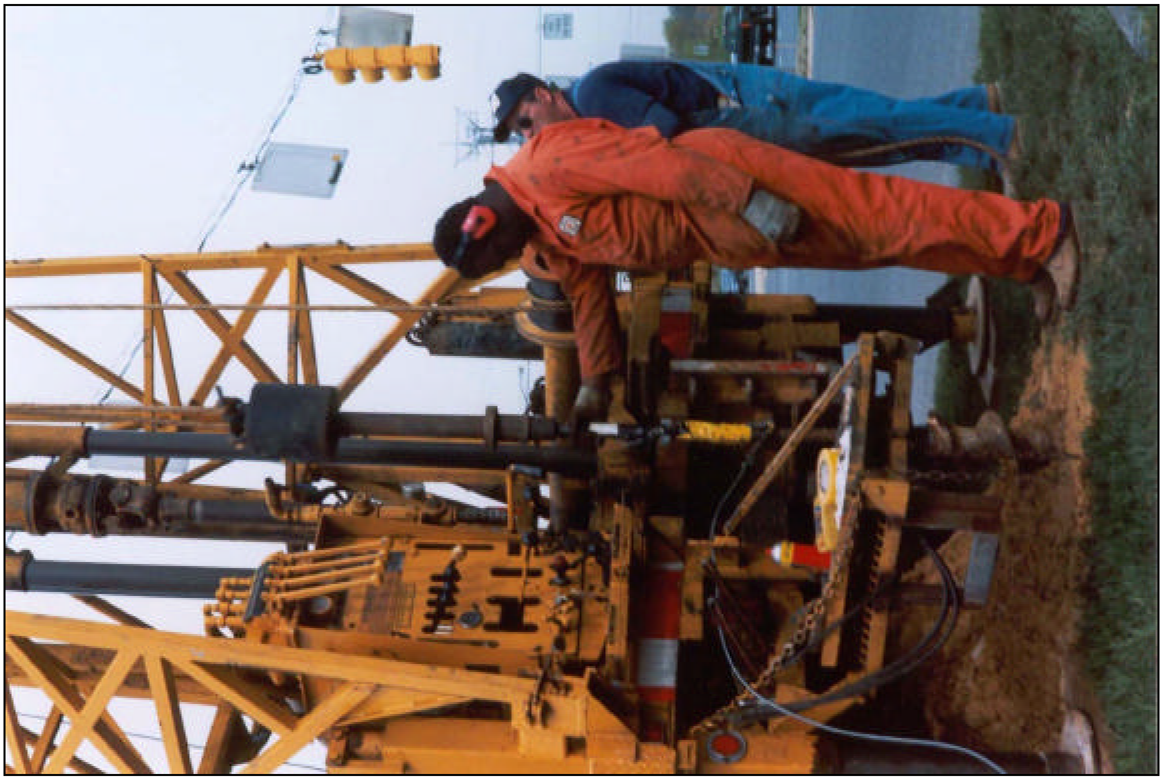


Fig. 5 Donut Hammer Test

Fig. 6 Instrumented Rod Detail