STANDARD PENETRATION TEST ENERGY MEASUREMENTS

ON

THE SEATTLE ASCE FIELD TESTING PROGRAM

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INTRODUCTION

The Geotechnical Division, Seattle Section of the American Society of Civil Engineers arranged to test several drill rigs while they were performing Standard Penetration Tests (SPT) at a single site near Seattle. A total of ten holes were drilled and sampled using the SPT. Nine holes were drilled on February 11, and one hole was drilled on March 11. During the first day's test three field engineers from Goble Rausche Likins and Associates, Inc. (GRL) performed tests at the site using two Pile Driving Analyzers (PDA) and one Hammer Performance Analyzer (HPA). On March 11, a GRL field engineer tested the single rig with both a PDA and an HPA.

The PDA was developed to make dynamic measurements of force and acceleration at the pile top during impact driving and process those measurements in real time. The transducers are conditioned, the signals digitized, displayed, and processed in a number of ways between each hammer blow. The PDA operator can examine the measurements, evaluate their quality and make modifications as necessary. The measurements are stored in digital form for later reprocessing. The various testing and analysis procedures are based on the Case Method which is described in Appendix A.

Appendix B contains detailed graphical and tabular test results for each SPT test hole. HPA results are presented with a sample digitized strip chart plot of the ram velocity verses time for each rig tested. Similarly, examples are given of the PDA's processed top force and velocity records plotted versus time for a typical blow at 25 feet penetration. The principal results are summarized in the Results Section of this report.

TEST DETAILS

Instrumentation

The SPT tests were performed using five different types of drill rods including; the AW-J, BW, BW-J, NW and the NW-J rod. Dynamic measurements were obtained using pairs of accelerometers and strain transducers mounted at about one foot from the top of the drill rods. The instrumented rod sections were inserted into the drive string at the top directly under the hammer anvil. Analog signals from the gages were conditioned, digitized, stored, and processed with a model PAK, Pile Driving Analyzer (PDA). Selected output from the PDA included values such as the measured force and velocity, calculated transferred energy, and the hammer operating rate.

Force and velocity records were viewed on the PDA's graphic screen to evaluate the data quality. Data from every hammer blow was stored in digital form for later reprocessing. The reprocessed data and the HPA measurements were the basis of the office analysis presented in this report. A schematic of the equipment setup is shown in Appendix A.

The HPA was used to measure the SPT ram velocity. The HPA senses the ram speed with doppler radar and displays it as a function of time on a strip chart. A review of the strip chart provides ram impact velocity from which the kinetic energy in the ram just prior to impact can be calculated. The impact velocities were read manually from the strip chart after returning from the field. Appendix A contains a brochure describing the capabilities of the HPA and Appendix

B contains a digitized segment of the strip chart taken for each SPT hole as an example of the measurement. The strip chart plot shows the velocity of the ram during a complete operating cycle.

Hammer and Driving System

Five different types of drill rigs were used to conduct SPT tests. They included three cathead and rope with safety hammer, two downhole hammers on wirelines with manual spooling winch, three automatic hammers, and two manual spooling winch operated safety hammers. For each SPT hole drilled, Table 1 gives some information on the details of the drilling setup and type of SPT drill rod used. The driving operation varied from one rig to the next. The effect of driving system differences on hammer performance will be discussed in the results for each SPT hole as appropriate.

Table 1 : Summary of A.S.C.E Field Testing

Spt Test Hole	Drilling/Hammer Setup	SPT Rod	Data Taken
A1	CME 75 downhole hammer and hollow stem auger	NW	HPA
A2	Cathead and rope with safety hammer	BW	HPA and PDA
A3	CME 75 automatic hammer	AW-J	HPA and PDA
A4	Cathead and rope with 300 lb. safety hammer	NW-J	HPA and PDA
B-1	Cathead and rope with safety hammer	BW-J	HPA
B-2	Automatic Hammer	AW-J	HPA and PDA
B-3	Safety hammer with spooling winch	NW-J	HPA and PDA
B-4	Downhole hammer on a wireline with manual release and a hollow stem auger		HPA
B-6	Mud rotary automatic hammer	AW-J	HPA and PDA

Soils

The influence of soil conditions on the SPT test results was not within the scope of this report. The recorded N-Value for each penetration is reported in Appendix B with the corresponding average ram impact velocities, transfer efficiencies, and hammer speeds. The N-value corrected for the driving system efficiency is also included with the other tabular data in Appendix B. This correction is described below.

Test Sequence

On February 11, 1995, three GRL engineers arrived at the SPT testing site at about 7 AM. SPT testing for the day was divided into a morning and an afternoon shift. SPT holes A-1, A-2, A-3, and A-4 were tested in the morning and B-1, B-2, B-3, B-4, and B-6 were tested in the afternoon. Tests were, generally, run at five foot increments of depth including 15, 20, 25, 30, 35, 40, 45, and 50 feet, but they were not run at every penetration for holes A1,B2, and B6. Test hole B-2 was tested at penetrations 13, 18, 23, 28, 33, 38, and 48 feet which differ slightly from the other holes.

The second test day was March 11, when one drill rig, C1, was tested. In this case, tests were run at 2.5 foot intervals to a depth of 25 feet except at 15 feet where a pressure meter test was substituted for the SPT. Problems were encountered with the force measurements and it was impossible to process the data satisfactorily. Therefore, these data are not presented.

Data Processing

The PDA conditions and digitizes the rod force and acceleration in the field and stores the resulting records in digital form. During these tests four records were stored for each hammer blow, two accelerations and two forces. Data was processed in the field so that measurements could be observed for quality, and energy values were obtained. In the field, it was noted that there were a few cases of unsatisfactory accelerometer performance. Re-examination in the office confirmed this suspicion and some of the data was reprocessed. Quality checks on the acceleration records were made by examining the unadjusted velocities at the end of a 100ms record where it is known that the velocity should be near zero. In addition, data quality was assessed by observing the proportionality of the force and velocity from the beginning of a record to the 2L/C time (time of reflection from the bottom of the sampler). The characteristics of the force and velocity records between ram impact and the 2L/C time consistently showed a decrease in rod impedance at locations where each successive rod section was connected. These apparent impedance changes were due to the small gaps at locations where two drill rod sections were screwed together.

During pile driving tests the energy transferred to the pile can be calculated using two methods. The first method uses both the force and velocity records obtained from dynamic testing to calculate the maximum energy,

$$EMX = \int_a^b F(t)\,v(t)\,dt$$

The value, a, corresponds to the time when the energy transfer begins and b is the time at which the energy transferred to the rod reaches a maximum value. This method is theoretically correct and contains no assumptions. It can be derived directly from the fundamentals of mechanics. The second method used to calculate the transferred energy uses the proportionality between force and velocity to express transferred energy in terms of only one measured quantity, the force. According to ASTM D 4633-86, the transferred energy can be written as follows:

$$EF2 = \frac{c}{EA}\int_a^w [F(t)]^2 dt$$

where E represents the Modulus of Elasticity of the drill rod material, A represents the cross-sectional area of the rod, and c is the stress wave speed in the rod. The integration begins at hammer impact time, a, and ends at a cut-off time, w, which corresponds with the first occurrence of a zero force after impact. It should be noted that the ASTM specification requires that the cut-off time, w, must be greater than (0.9)2L/C and less than (1.2)2L/C. Several corrections to the EF2 value are specified in ASTM D 4633-86. The value of EF2 has been found to frequently be an inaccurate representation of the energy transferred from the hammer to the rod. The results presented for EF2 efficiencies are strictly based on the hammer blows which complied with the ASTM requirements.

FIELD RESULTS

Definition of Result Terminology

Energy and impact velocity results were found to be most useful when expressed in relation to the theoretical potential energy of the ram before free fall and the actual kinetic energy of the ram just before impact. The following efficiencies were used to describe the operation of each SPT testing system:

$$\text{Ram Efficiency} = \frac{\text{Kinetic Energy of the ram just prior to impact}}{\text{Potential energy of the ram before free fall}}$$

$$\text{Transferred Energy Efficiency} = \frac{\text{Measured Energy Transferred to the rod}}{\text{Potential energy of the ram before free fall}}$$

$$\text{Ram-Rod Transfer Efficiency} = \frac{\text{Transferred Energy Efficiency}}{\text{Ram Efficiency}}$$

The most important value is the Transferred Energy Efficiency since it is this quantity that is used in adjusting the N-values. The other efficiencies are useful in understanding SPT driving system operation.

Test Results

The detailed results of the measurements are given in Appendix B. For each drill rig tested the measurements are discussed briefly. Tabular results are presented that summarize the data obtained for each rig at each depth. A sample force and velocity record is shown as is an example of of the ram velocity measurement. In the tabular data, the average measured quantities ram impact velocity, EMX efficiency, EF2 efficiency and blows per minute are given for each test depth together with the coefficient of variation of these data. Also the recorded N-value is tabulated together with the N-value corrected to the 60% efficiency using the Schmertmann correction. This correction states that the N-value for a standard 60% efficiency is

$$N_{60} = \frac{e_m}{60} N_m$$

where e_m is the measured transferred energy efficiency and N_m is the measured blow count.

Transferred energy efficiencies for both EMX and EF2 computational procedures are given in the tables of results in Appendix B. These data are summarized in Table 2. In addition to the mean efficiencies for HPA, EMX, and EF2 and the mean operating speeds, the coefficients of variation are also given for each quantity. The amount of data upon which results are based is shown in the number of blows processed.

The summary results given in Table 3 are based on the EMX computation. In the measurements at this site, there was little difference in the results for the two methods, however, experience has shown that the EMX results are the most reliable.

Table 2 : SPT Demonstration Program Result Summary 1

Rig	HPA		EMX Efficiency		EF2 Efficiency		BPM		No. of Data Sets	No. of Hammer Blows
	Effic. %	COV %	Effic. %	COV %	Effic. %	COV %	BPM (Bl/min.)	COV %		
A1	41.04	5.67	-	-	-	-	-	-	4	124
A2	63.57	1.44	51.43	4.81	55.71	3.63	52.59	6.28	8	270
A3	96.16	0.89	81.43	5.82	80.71	6.80	51.00	0.64	8	228
A4	77.70	1.19	74.77	3.28	66.08	8.11	46.27	4.92	5	76
B1	74.76	4.17	-	-	-	-	-	-	9	342
B2	99.00	3.06	68.57	10.87	67.43	8.73	41.72	1.05	5	59
B3	24.67	7.18	23.14	17.89	20.82	9.69	44.88	3.66	9	414
B4	29.38	7.82	-	-	-	-	-	-	8	420
B6	91.01	2.68	72.86	5.88	74.29	6.08	57.96	1.39	4	44

Table 3 : SPT Demonstration Program Result Summary 2				
Rig	Transferred Energy Efficiency %	HPA Ram Efficiency %	Ram-Rod Transfer Efficiency %	Hammer Speed BPM
A1	-	41.04	-	-
A2	51.43	63.57	80.90	52.59
A3	81.43	96.16	84.68	51.00
A4	74.77	77.70	96.24	46.27
B1	-	74.76	-	-
B2	68.57	99.00	69.26	41.72
B3	23.14	24.67	93.79	44.88
B4	-	29.38	-	-
B6	72.86	91.01	80.05	57.96

DISCUSSION OF RESULTS

The most noticeable characteristic of the automatic hammer SPT testing rigs (A-3, B-2, and B-6) was the ram efficiency ranging between 91% and 99%. This indicates that the automatic hammer is able to effectively create a free fall condition. The transfer efficiency for the two CME hammers averaged 77%. The other automatic hammer was somewhat lower at 69%. These values seem to be somewhat lower than what is usually observed due to a Ram-Rod transfer efficiency that was lower than usual.

The cathead and rope operated safety hammers (A2 and A4) had transfer efficiencies of 51% and 75%. It should be noted that A4 had a 300 lbs. ram and was measured to operate with a very efficient ram-rod energy transfer.

The hammers that were driven by a manually operated Spooling Winch Hammer (A-1,B-3, and B-4) had HPA efficiencies of 41%, 25%, and 29%. The transfer efficiency was only measured on B3 where it was 23%. The data obtained from the safety hammer showed that the spooling winch was systematically engaged prior to impact causing a substantial reduction of the impact velocity.

APPENDIX A:

AN INTRODUCTION INTO DYNAMIC PILE TESTING METHODS

BACKGROUND

Since the mid-1960s research has been conducted at Case Institute of Technology in Cleveland, Ohio with the objective of improving pile installation and construction control methods using electronic measurement and modern analysis methods. This work had been supported by the Ohio Department of Transportation and the Federal Highway Administration.

In 1973, the research results were introduced into practice. Professor G. G. Goble, who had been the principal investigator at Case, founded Pile Dynamics, Inc. a company which manufactures - among other devices - the Pile Driving Analyzer™ (PDA). Together with his former research assistants he also founded Goble Rausche Likins and Associates, Inc. (GRL) a consulting engineering firm specialized in the dynamic measurement and analysis methods of piles.

Pile Dynamics gradually improved the PDA technology, always searching for and utilizing advances in electronic and computer technology. In addition, new devices were built and introduced into the market. GRL, on the other hand, developed methods and software for the analysis of the measured quantities. It is the intent of this paper to summarize both analytical and measurement tools available to the civil engineer.

RESULTS FROM DYNAMIC TESTING

The following are the main objectives of dynamic pile testing (or monitoring).

- Bearing Capacity at the time of testing. For the prediction of a pile's long term bearing capacity, measurements are taken during restriking.
- Dynamic Pile Stresses during pile driving. In order to limit the possibility of pile damage, stresses must be kept within certain bounds. For concrete piles both tension and compression stresses are important.
- Pile Integrity often must be checked both during and after pile installation.
- Hammer Performance must be checked for productivity and construction control.

MEASUREMENTS

The basis for the results calculated by the PDA are pile top force and velocity signals, obtained using piezoelectric accelerometers and bolt-on strain transducers attached to the pile near its top. The PDA conditions and calibrates these signals and immediately computes average pile force and velocity. Using Case Method solutions, the PDA calculates the results described in the following section.

Other measurements are sometimes also required. The ram velocity may be directly obtained using radar technology in the Hammer Performance Analyzer™ (HPA). For open end diesel hammers, the time between two impacts indicates the magnitude of the fall height. This information is measured and calculated by the Saximeter™. Furthermore, the combustion pressure may be measured in diesels for proper wave equation modeling. Acceleration measurements taken on a helmet in addition to standard pile top force and velocity measurements yield pile top cushion stiffness information.

The Pile Integrity Tester (P.I.T.) can be used to evaluate damage to piles which may have occurred during driving or casting. It should also be mentioned that this so-called "Low Strain Method" of integrity testing requires only the measurement of acceleration at a pile top. The stress wave producing impact is then generated by a small hand-held hammer.

ANALYTICAL SOLUTIONS

BEARING CAPACITY

Wave Equation

GRL has prepared a program, GRLWEAP, which provides for a truly analytical solution, *i.e.* it does not require measurements and provides the user with a functional relationship between both bearing capacity and pile stress and the blow count. These results can be adjusted or calibrated if measurements of pile top quantities are available. However, the real strength of the traditional wave equation approach lies in a prediction of driving behavior and in the selection of an optimal driving system.

Case Method

The Case Method is a closed form solution based on a few simplifying assumptions such as ideal plastic soil behavior and an ideally elastic and uniform pile. Given the measured pile top force F(t) and pile top velocity v(t), the total soil resistance is

$$R(t) = \tfrac{1}{2}\{[F(t) + F(t_2)] + Z[v(t) + v(t_2)]\} \qquad (1)$$

where

- Z EA/c is the pile impedance,
- t_2 time t + 2L/c
- L pile length below gages
- c $(E/\rho)^{1/2}$ is the speed of the stress wave
- E elastic modulus of the pile
- ρ pile mass density
- A pile cross sectional area

The total resistance consists of a dynamic and a static component. Thus

$$R_s(t) = R(t) - R_d(t) \qquad (2)$$

The static resistance component is, of course, the desired pile bearing capacity. The dynamic component may be computed from a soil damping factor, J, and a pile toe velocity, $v_t(t)$ which is conveniently calculated for the pile toe. Using wave considerations, this approach leads immediately to the dynamic resistance

$$R_d(t) = J[F(t) + Zv(t) - R(t)] \qquad (3)$$

and finally to the static resistance by means of Equation 2. This solution is simple enough to be evaluated "in real time", *i.e.* between hammer blows, using the PDA. However, the assumption of a soil damping constant must be made and the time, t, has to be selected. Often, t is selected such that the maximum static resistance, RMX, is calculated. The damping constant, J, may not be needed if the time, t, is chosen such that the $R_d(t)$ term vanishes. One calls the resulting capacity value RA2.

CAPWAP

This method (Case Pile Wave Analysis Program) combines the wave equation pile and soil model with the Case Method measurements. Thus, the solution includes not only the total and static bearing capacity values but also the skin friction, end bearing, damping factors and soil stiffness. The method iteratively determines a number of unknowns by signal matching. While it is necessary to make hammer performance assumptions for a GRLWEAP analysis, the CAPWAP® program works with the pile top measurements. Furthermore, while GRLWEAP and Case Method require certain assumptions regarding the soil behavior, CAPWAP calculates these soil parameters.

STRESSES

The wave equation and CAPWAP solutions include stresses along the pile. For the PDA, field results include the pile top stress directly from the measurement and, for concentrated end bearing, the stress at the pile toe from Equation 1.

For concrete piles the maximum tension stress is also of great importance. It occurs at some point below the pile top. The maximum tension stress can be computed from the pile top measurements by considering the magnitude of both upward and downward traveling waves, W_u and W_d.

$$W_u = \tfrac{1}{2}[F(t) - Zv(t)] \qquad (4)$$

$$W_d = \tfrac{1}{2}[F(t) + Zv(t)] \qquad (5)$$

If any one of these waves is negative, a tension wave exists. It must be checked whether the wave traveling in the opposite direction is sufficiently compressive to reduce the net tension to allowable levels. The PDA also performs this calculation.

PILE INTEGRITY

High Strain Tests

Stress waves in a pile are reflected wherever the impedance (Z=EA/c) changes. The reflected waves arrive at the pile top at a time which depends on the location of the change. The reflected waves cause changes in both pile top force and velocity. The magnitude relative change of the pile top variables allows to determine the extent of the cross sectional change. Thus, with β_i being a relative integrity factor which is unity for no impedance change and zero for the pile end, the following can be calculated by the PDA.

$$\beta_i = (1 - \alpha_i)/(1 + \alpha_i) \qquad (6)$$

with

$$\alpha_i = ½(W_{ur} - W_{ud})/(W_{di} - W_{ur}) \qquad (7)$$

where

- W_{ur} is the upward traveling wave at the onset of the reflected wave. It is caused by resistance.
- W_{ud} is the upwards traveling wave due to the damage reflection.
- W_{di} is the maximum downward traveling wave due to impact.

Low Strain Tests (P.I.T.)

The pile top is struck with a held hand hammer and the resulting pile top velocity is measured, displayed and interpreted for signs of wave reflections. In general, a comparison of the reflected acceleration leads to a relative measure of extent of damage, again the location of the problem is indicated by the arrival time of the reflection. An approximate pile profile can be calculated from low strain records using the P.I.T.WAP.

HAMMER PERFORMANCE

The PDA can very simply calculate the energy transferred to the pile top.

$$E(t) = \int_0^t F(t)v(t)\,dt \qquad (8a)$$

The maximum of the E_t curve is the most important information for an overall evaluation of the performance of a driving system. This EMX or ENTHRU value allows for a classification of the hammer's performance, using:

$$e_t = EMX/E_r \qquad (8b)$$

where E_r is the hammer's rated energy.

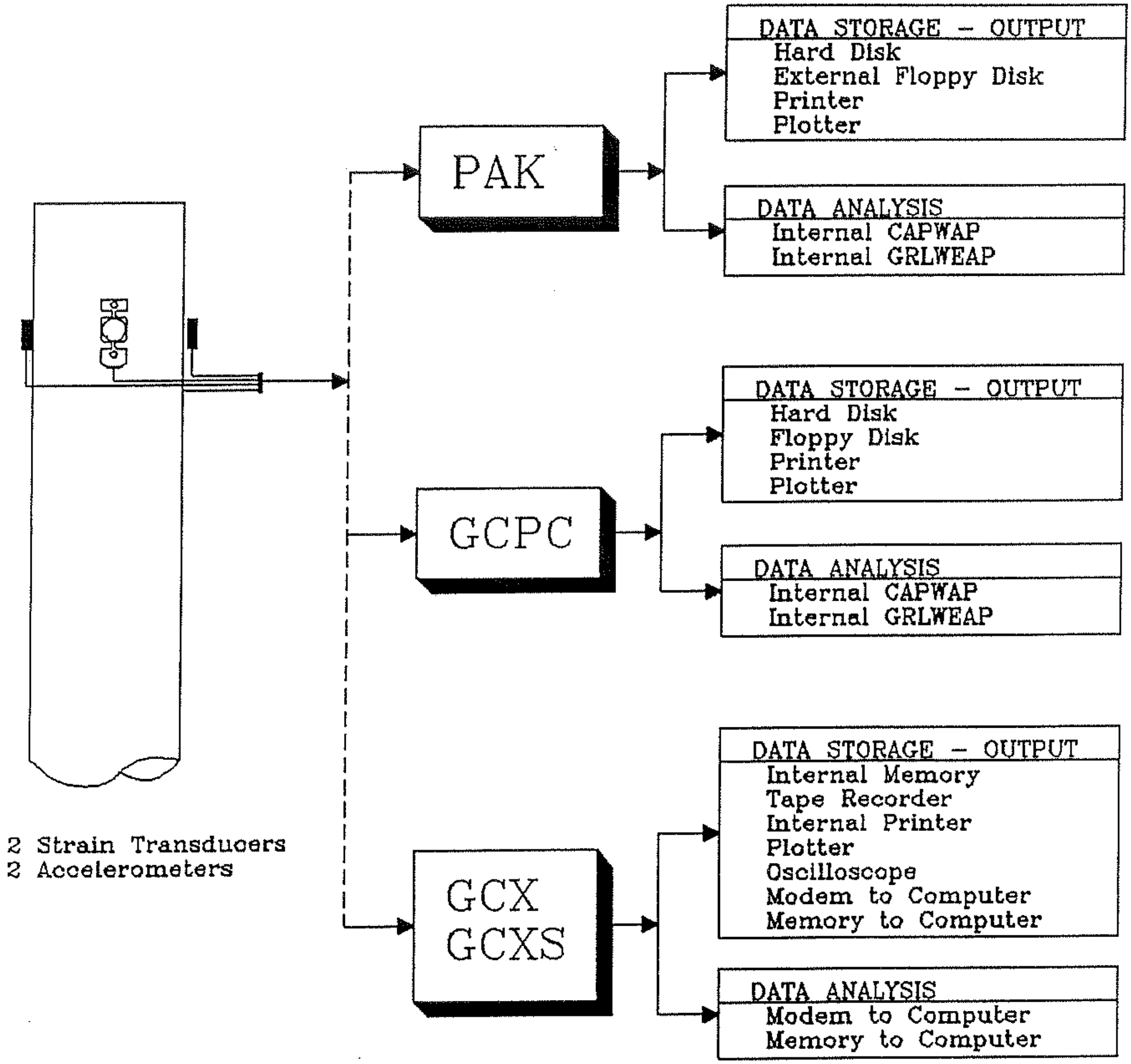
The Saximeter™ calculates the stroke from an open end diesel using

$$h = (g/8)\,T^2 - h_l \qquad (9)$$

where

- g earth gravitational acceleration,
- T time between two blows,
- h_l a stroke loss value due to gas compression and time losses during impact (usually 0.3 ft or 0.1 m).

Pile Driving Analyzer System



APPENDIX B

A-1

The first hole was drilled with a CME 75 drill rig. A 140 lb. downhole hammer with a manually operated wireline was used to advance an NW rod. Only HPA measurements were made by attaching a target to the top of the downhole hammer. This driller did not want to use the downhole hammer under water so he drove through the NW rod. It was only possible to make measurements at four depths. The measured impact velocity averaged 8.1 ft/s for four SPT test penetrations. The calculated "ram efficiency" was 41% for this downhole hammer.

A-2

The SPT test for hole A-2 was performed with a cathead and rope system. SPT tests were run at eight penetrations with a 140 lb. safety hammer and a standard BW rod. The safety hammer ram showed a constant acceleration (see data for A2) indicated by the straight line of increasing velocity in the HPA data. The average impact velocity was 10.1 ft/s which indicates a ram efficiency of 63.6%. The efficiency of energy transfer into the rod was 51.4% with a hammer operating speed of 52.6 blows per minute. Another interesting form of the results is the ratio of the transfer efficiency to the ram efficiency. This provides a measure of the losses at impact between the hammer and the SPT rod and is called "ram-rod transfer efficiency". This cathead and rope rig had a ram-rod transfer efficiency of 81% which means that 19% of the energy delivered by the ram was lost at impact. The energy calculated by EF2 was very similar to that determined by EMX.

A-3

The third SPT test hole was drilled with a CME automatic hammer to advance AW-J rods. Eight SPT tests were run and the average impact velocity was 12.4 ft/s. The corresponding average ram efficiency was 96.2% and the average efficiency of energy transfer to the ram was 81.4%. A ram efficiency of 96% shows that the automatic hammer creates hammer free fall with minimal losses. The ram-rod transfer efficiency was 85% , indicating that 15% of the energy contained in the ram was lost at impact. The average hammer operating speed was 51 blows per minute.

A-4

The last hole tested during the morning shift was A-4. A cathead and rope was used with a 300 lb. safety hammer. The weight of this safety hammer is more than twice the usual 140 lb. weight used by other SPT testing systems. The drill rod was a standard NW-J rod. Average impact velocity was 11.2 ft/s with a corresponding ram efficiency of 77.7%. The efficiency of energy transfer to the rod was 74.8% thus making the ram-rod transfer efficiency equal to 96%. The high ram-rod transfer efficiency indicates that there are minimal losses in the impact between the larger ram and the rod.

B-1

The first afternoon test used a cathead and rope with a 140 lb. safety hammer. The SPT rods were standard BW-J rods. PDA measurements were not taken for this hole because the rods had not been prepared for instrumentation. The HPA measured an average impact velocity of 11.0 ft/s and the resulting ram efficiency was found to be 74.8%.

B-2

Hole B-2 was tested with a BK-81 automatic hammer. A 140 lb. hammer was used to advance AW-J rods to seven different SPT testing penetrations. The HPA trace of ram velocity showed a constant acceleration of the ram to the average final impact velocity of 12.6 ft/s. The corresponding ram efficiency was found to be 99%. High ram efficiency again indicates that the automatic hammer is able to create an almost perfect free fall for performing SPT tests. The transferred energy efficiency was 68.6% resulting in a ram-rod transfer efficiency of 69%. The operating speed of the hammer averaged 41.7 blows per minute.

B-3

SPT tests were performed at nine penetration depths using a safety hammer driven by a spooling winch. The HPA measured an average impact velocity of 6.3 ft/s. The HPA's trace of the rams movement from its resting position to impact (see data for B-3) showed a velocity with a reasonably constant slope rising to a rounded peak. The velocity then decreased until impact occurred at a velocity considerably lower than the peak ram velocity. To induce this behavior the operator engaged the winch somewhat before impact. In all cases, the winch operation showed the behavior illustrated by this measurement and the impact velocities were quite constant. Experience has shown that a ram-to-SPT rod impact is characterized by a sharp change in the velocity and in this case it was easily recognized. The ram efficiency was 24.7% and the transferred energy efficiency was 23.1%. This indicates that there was minimal loss of energy during impact of the ram to the rod but significant energy loss due to ram operation. The ram-rod transfer efficiency was 94% with an average hammer speed of 44.9 blows per minute.

B-4

A downhole hammer was used to perform tests at eight penetrations. It weighed 140 lbs. and was operated by a wireline with a manual release spooling winch. The average impact velocity of the ram was 6.9 ft/s which is comparable to test hole A-1 with an impact velocity of 8.1 ft/s. The ram efficiency of this downhole hammer was 29.4%.

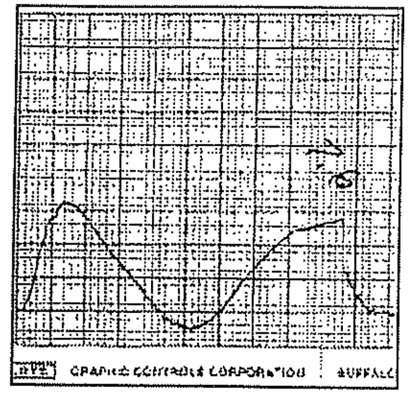
B-6

The last SPT hole was tested with a Skid Rig composed of a mud rotary drill and a 140 lb. CME automatic hammer. AW-J rods were driven to five penetrations for SPT testing. The average impact velocity of the ram was 11.9 ft/s with a corresponding ram efficiency of 91%. The average energy transfer efficiency was 72.9% which resulted in a ram-rod efficiency of 80%. TheCME 45 hammer operated at an average speed of 58 blows per minute.

A1 - Downhole Hammer CME 75

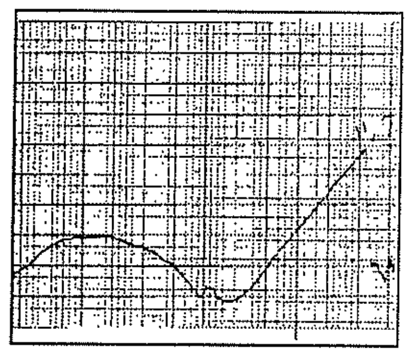
with hollow stem auger

Depth (ft.)	N-Value	Impact Velocity (ft/sec) AVG	COV
10.0	42	7.7	0.035
15.0	35	7.7	0.043
20.0	29	8.8	0.025
25.0	18	8.3	0.030



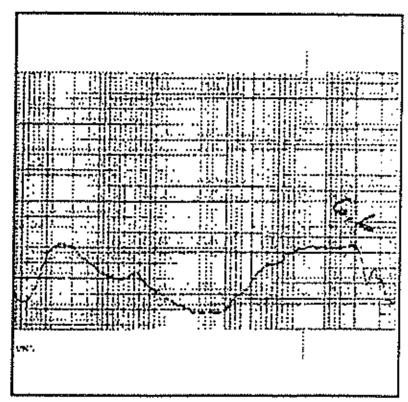
B1 - Cathead and Rope and Safety Hammer

Depth (ft.)	N-Value	Impact Velocity (ft/sec) AVG	COV
10.0	16	10.3	0.032
15.0	8	10.8	0.027
20.0	3	10.4	0.023
25.0	50	11.7	0.024
30.0	79	10.6	0.123
35.0	53	11.3	0.017
40.0	40	11.4	0.015
45.0	11	11.3	0.015
50.0	82	10.9	0.0245



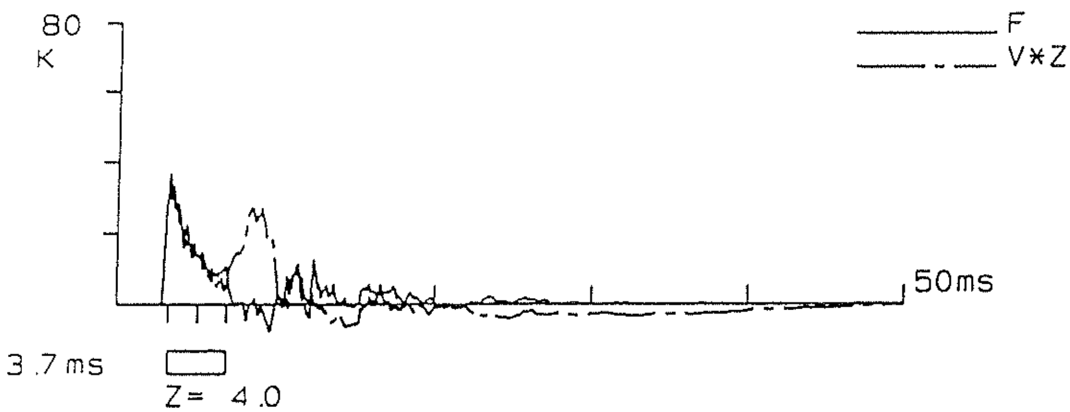
B4 - Downhole Hammer w/spooling winch and hollow stem auger

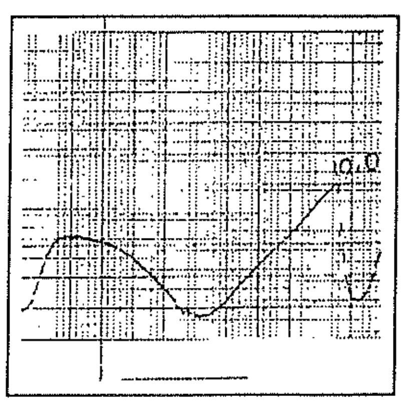
Depth (ft.)	N-Value	Impact Velocity (ft/sec) AVG	COV
15.0	50/3"	8.1	0.064
20.0	8	6.8	0.057
25.0	67	7.0	0.074
30.0	80	6.3	0.042
35.0	65	6.3	0.045
40.0	50/2"	6.8	0.045
45.0	50/1"	6.6	0.038
50	50/4"	7.1	0.041



A2 - Cathead and Rope with Safety
Hammer

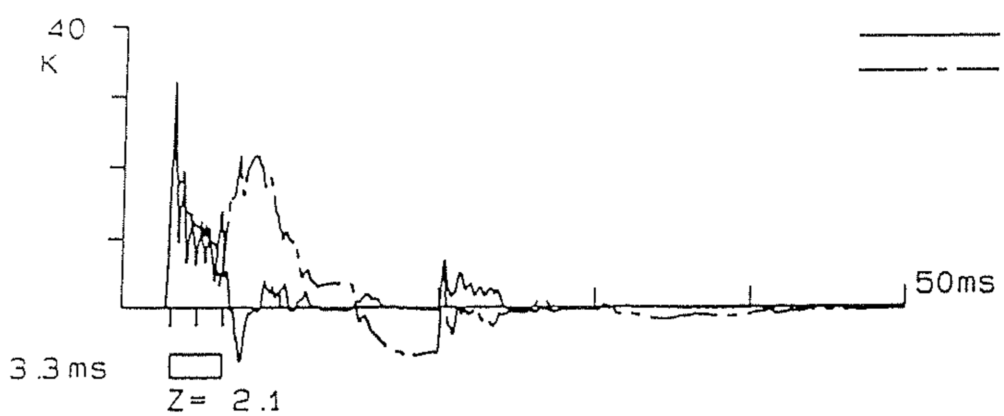
Depth (ft.)	N-Value	Corrected N-Value	Impact Velocity ft/sec		Efficiency EMX/(.35kft)		Efficiency EF2/(.35kft)		BPM (blows/min.)	
			AVG	COV	AVG	COV	AVG	COV	AVG	COV
15	6	5	10.0	0.024	0.49	0.000	0.54	0.000	47.00	0.000
20	9	7	10.0	0.040	0.49	0.059	0.54	0.105	47.40	0.051
25	24	21	10.4	0.023	0.51	0.056	0.57	0.050	52.30	0.028
30	36	29	10.1	0.043	0.49	0.059	0.54	0.053	54.40	0.040
35	25	23	10.1	0.024	0.54	0.053	0.57	0.050	54.10	0.038
40	74	67	10.0	0.030	0.54	0.053	0.54	0.053	54.50	0.026
45	45	41	10.0	0.024	0.54	0.053	0.54	0.053	54.30	0.041
50	51	44	10.3	0.021	0.51	0.056	0.60	0.048	56.70	0.028

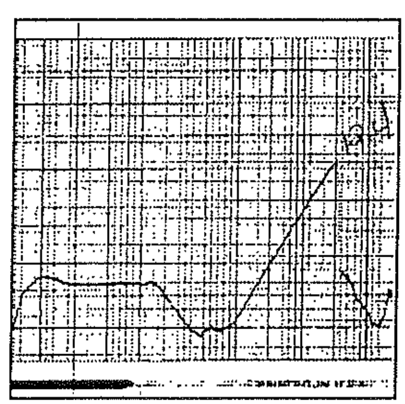




A3 - Automatic Hammer

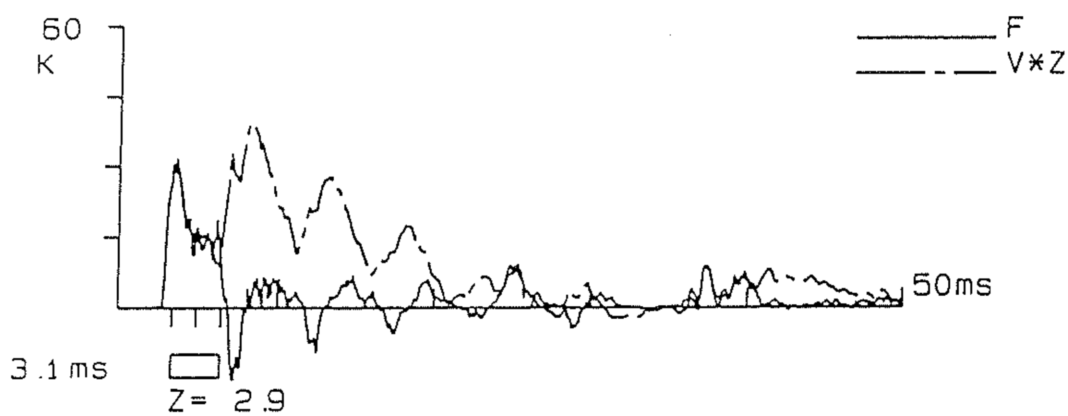
Depth (ft.)	N-Value	Corrected N-Value	Impact Velocity (ft/sec)		Efficiency EMX/(.35kft)		Efficiency EF2/(.35kft)		BPM (blows/min.)	
			AVG	COV	AVG	COV	AVG	COV	AVG	COV
15	6	8	12.2	0.01	0.83	0.06	0.71	0.04	51.20	0.011
20	10	13	12.5	0.00	0.80	0.03	0.71	0.04	51.44	0.012
25	17	23	12.4	0.00	0.83	0.03	0.83	0.01	51.25	0.008
30	126	168	12.6	0.01	0.80	0.10	0.83	0.03	50.34	0.009
35	22	34	12.4	0.00	0.91	0.03	0.83	0.01	50.98	0.011
40	13	18	12.5	0.00	0.83	0.06	0.86	0.01	51.12	0.013
45	11	14	12.4	0.01	0.74	0.19	0.83	0.01	50.94	0.014
50	23	30	12.5	0.01	0.77	0.09	0.86	0.03	50.70	0.012

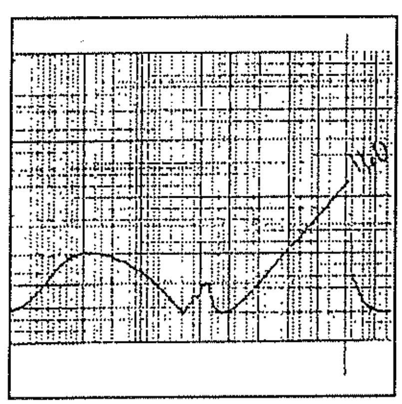




A4 - Cathead and Rope Safety Hammer with Hollow Stem Auger

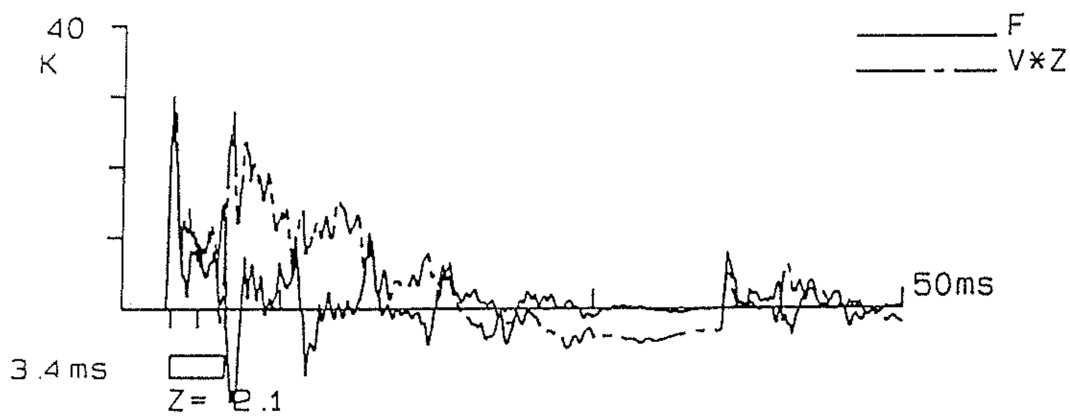
Depth (ft.)	N-Value	Corrected N-Value	Impact Velocity (ft/sec)		Efficiency EMX/(.75kft)		Efficiency EF2/(.75kft)		BPM (blows/min.)	
			AVG	COV	AVG	COV	AVG	COV	AVG	COV
15	8	10	11.0	0.041	0.76	0.053	0.57	0.033	46.96	0.023
20			Data Not Acceptable							
25	16	19	11.2	0.019	0.71	0.264	0.63	0.043	42.37	0.008
30	8	10	11.4	0.020	0.73	0.078	0.69	0.106	49.21	0.023
35	12	15	11.2	0.015	0.77	0.140	0.69	0.065	47.30	0.015
40	32	41	11.1	0.025	0.77	0.127	0.72	0.085	45.52	0.019
45			Data Not Acceptable							
50			Data Not Acceptable							

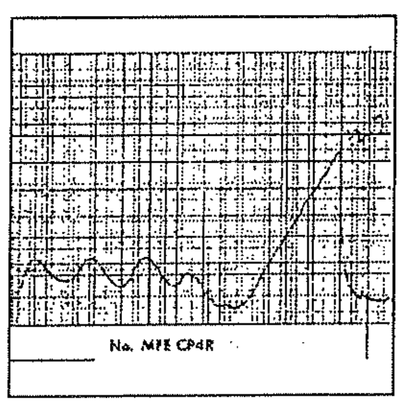




B2 - Automatic Hammer

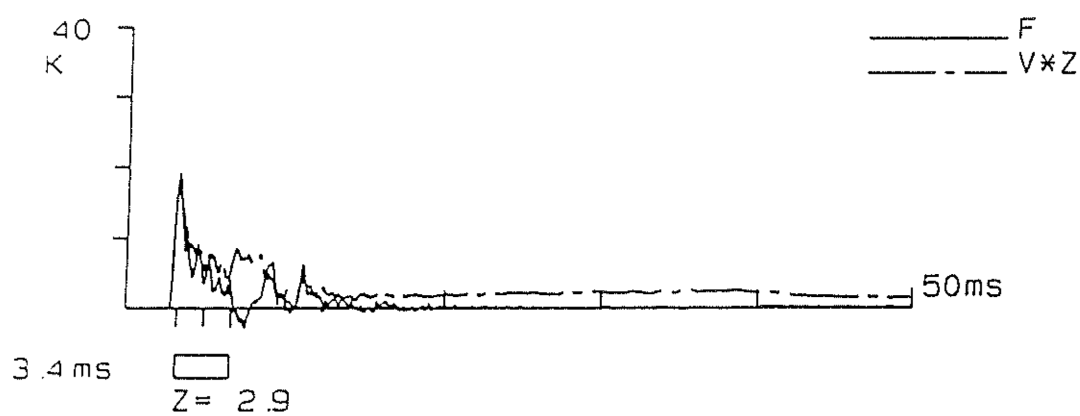
Depth (ft.)	N-Value	Corrected N-Value	Impact Velocity (ft/sec)		Efficiency EMX/(.35kft)		Efficiency EF2/(.35kft)		BPM (blows/min.)	
			AVG	COV	AVG	COV	AVG	COV	AVG	COV
13			Data Not Acceptable							
18	4	4	13.0	0.012	0.54	0.158	0.57	0.025	41.00	0.013
23	8	10	12.6	0.025	0.71	0.080	0.69	0.042	42.30	0.016
28			Data Not Acceptable							
33	13	15	11.9	0.036	0.69	0.083	0.71	0.080	41.50	0.011
38	14	17	12.7	0.021	0.74	0.038	0.66	0.043	41.90	0.016
48	20	25	12.9	0.037	0.74	0.077	0.74	0.077	41.90	0.016

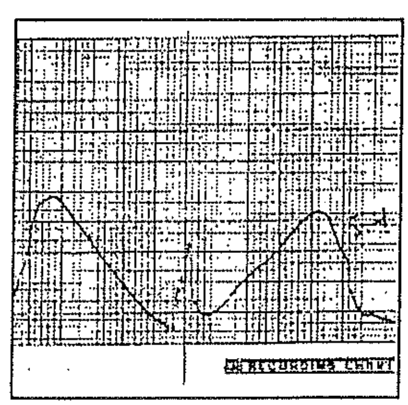




B3 - Safety Hammer with Mechanical Winch

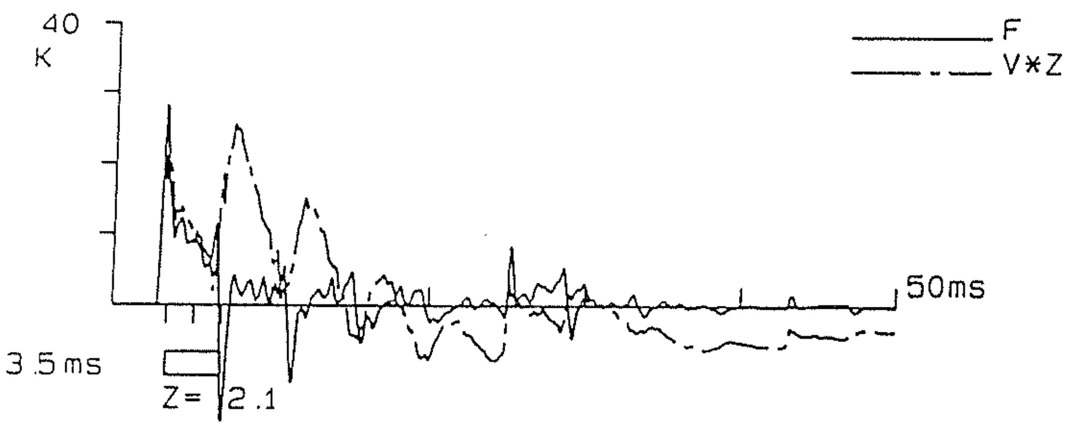
Depth (ft.)	N-Value	Corrected N-Value	Impact Velocity (ft/sec)		Efficiency EMX/(.35kft)		Efficiency EF2/(.35kft)		BPM (blows/min.)	
			AVG	COV	AVG	COV	AVG	COV	AVG	COV
12	64	27	5.9	0.084	0.25	0.173	0.17	0.155	46.08	0.140
15	200	93	6.6	0.072	0.28	0.127	0.21	0.127	43.11	0.028
20	7	3	7.0	0.084	0.28	0.310	0.24	0.259	42.94	0.071
25	150	70	6.2	0.102	0.28	0.194	0.21	0.125	43.74	0.088
30	120	39	5.9	0.083	0.20	0.243	0.19	0.099	46.05	0.096
35	150	51	6.5	0.113	0.20	0.105	0.21	0.102	44.78	0.070
40	300	89	6.8	0.136	0.18	0.183	0.22	0.161	48.38	0.130
45	120	36	5.5	0.128	0.18	0.255	0.22	0.329	44.98	0.067

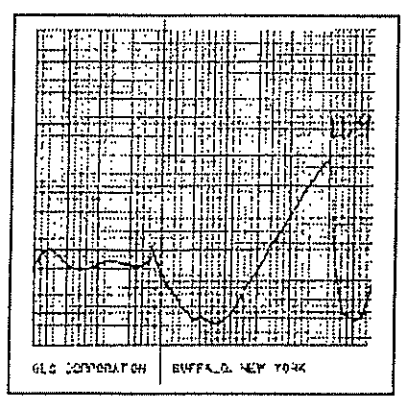




B6 - Mud Rotary Automatic Hammer

Depth (ft.)	N-Value	Corrected N-Value	Impact Velocity (ft/sec)		Efficiency EMX/(.35kft)		Efficiency EF2/(.35kft)		BPM (blows/min.)	
			AVG	COV	AVG	COV	AVG	COV	AVG	COV
10.5	4	5	12.6	0.004	0.71	0.040	0.69	0.017	58.95	0.007
15.5	3	3	11.7	0.007	0.69	0.042	0.71	0.004	58.40	0.014
20			Data Not Acceptable							
25	19	25	12.1	0.019	0.80	0.036	0.77	0.015	57.69	0.013
35	18	21	12.0	0.016	0.71	0.080	0.80	0.011	56.80	0.017





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