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SPT ENERGY TRANSFER MEASUREMENTS FOR LIQUEFACTION EVALUATIONS IN THE NORTHEAST

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Abstract

Energy measurements were made during Standard Penetration testing at Northeast locations with 16 drilling rigs having various energy transfer mechanisms including automatic safety hammers, wire line safety hammers, rope and cathead safety hammers and donut hammers. The energy measurements were used to correct the field N values to the standard 60% reference energy transfer. Examples are provided to illustrate the significant effect which the energy transfer efficiency has when working with Building Codes. The uncertainty regarding the use of field N values as opposed to energy corrected N values when using the codes is discussed.

Keywords

Standard Penetration test, liquefaction, energy transfer, automatic hammers, donut hammers, safety hammers, New England, New York City, PDA, building codes.

INTRODUCTION

Energy transfer measurements were made during Standard Penetration testing with a total of 16 drilling rigs. Many of the rigs were tested multiple times on different sites. The SPT mechanisms included 5 automatic safety hammers, 5 wire line safety hammers, 2 rope and cathead safety hammers and 4 donut hammers. Sites were located in Massachusetts, Rhode Island, Connecticut and New York. The energy measurements were used to correct the field N values to the standard reference of 60% energy transfer. This correction improved the accuracy of analyses for liquefaction. On sites where scheduling required the use of several drilling rigs, the energy tests helped distinguish variations caused by site conditions from those caused by the SPT mechanisms.

The purpose of this paper is to compare energy transfer values measured for many types of equipment at Northeast sites with those reported in the literature for other sites throughout the country, and to show the significant effect that energy transfer corrections can have on SPT values with regard to design criteria involving building codes and sophisticated analyses in the Northeast.

ENERGY TESTING METHODS

All energy tests were conducted by Heller and Johnsen personnel using an instrumented NW rod section manufactured by Pile Dynamics, Inc., Cleveland, Ohio. Normally, energy measurements were taken at the top of the drill string in which case the instrumented NW rod was attached immediately beneath the hammer. This top rod was instrumented with two strain gages and two piezoresistive accelerometers. The strain gages and accelerometers were connected to a Pile Driving Analyzer (PDA) on which the field engineer recorded the data.

One project involved energy measurements at depths of 80 feet using a waterproofed instrumented NWJ rod manufactured by Pile Dynamics, Inc. Whereas, the top test adds about fifteen minutes to the drilling time, the bottom test added 3 hours. The cables ran up the annulus between the drill string and a 4-inch I.D. casing. A high degree of care was exercised to protect the cables. The deep tests were run simultaneously with top tests with all cables connected to a single PDA.

The term transferred energy efficiency is defined as the measured strain energy delivered to the drill string divided by the potential energy of the 140 pound weight free falling 30 inches, that is 4200 inch-pounds. Other studies have measured the maximum velocity of the weight to compute the kinetic energy. The term ram efficiency is the kinetic energy of the weight immediately prior to impact divided by the potential energy of the weight. The ram-rod efficiency is defined as the transferred energy efficiency divided by the ram efficiency.

The commonly employed procedures for correcting field measured Standard Penetration test values (Nfield) to corrected for energy transfer values (Nc) is by, first, determining the ratio of the energy transfer efficiency, Ne by

$$Ne = Efield/60$$

Where 60 is the reference efficiency value and, second by

$$Nc = Ne * Nfield$$

There is no fixed standard for the rate of drop. The commonly used rates vary between 45 and 55 drops per minute.

RESULTS FOR SPT HAMMER TYPES

Testing was conducted on CME and Diedrich automatic safety hammers, Mobil spooling winch safety hammers, rope and cathead safety hammers and donut hammers.

The CME automatic hammer is a hydraulically powered chain lift device. The drive weight lifting and dropping sequence is activated when the operator opens a hydraulic valve. The manufacturer reports a ½ inch tolerance on the 30-inch free fall (Riggs, C. et. al., 1984). Seven energy tests were conducted on three CME automatic hammers. On one rig the drop rate of the hammer was reduced from 55 to 38 drops per minute, with a resulting decrease in transferred energy from 72 to 63%, respectively. When operated at 52 to 55 drops per minute the transferred energies varied between 69 and 83% for the three rigs.

The Diedrich automatic hammer is also activated by a hydraulically powered chain lift device. On the Diedrich hammer, the chain rotates continually during the testing and has pins that pick up and drop the weight. Five energy tests were conducted on two Diedrich automatic hammers. The drop rates were varied from 25 to 40 and 28 to 45 drops per minute on the two rigs with no appreciable change in transferred energy. The transferred energies varied from 68 to 69% for one rig, and from 55 to 57% for the other rig.

The rope and cathead safety hammer consists of a narrow cylindrical 140 pound weight that is encased in a steel guide tube. The weight is lifted by a rope wrapped 2 times around a cathead. The rope slips on the cathead as the weight drops. Three energy tests were run on two rope and cathead safety hammers with a variation in transferred energy of 63 to 66%. The drop rates varied between 53 and 61 drops per minute.

The wire line safety hammer is similar to the rope and cathead safety hammer except that the weight is lifted by a spooling wireline. For each drop the operator pulls a lever twice, to lift and release the weight. Nine energy tests were run on seven wireline safety hammers. The transferred energies varied from 34 to 72%. The 72% transfer was the only test result over 50%. The drop rates varied between 46 and 60 drops per minute.

The donut hammer is a short, wide cylindrical weight that is lifted by a rope wrapped around a cathead. Its poor efficiency and wide variability has been the subject of numerous studies (Ireland, H. O., et. al., 1970). A total of 6 tests were run on three donut hammers with energy transfers varying from 31 to 53%. The drop rates varied between 45 and 61 drops per minute.

The reader is referred to other studies (Batchelor, C., et. al., 1995 and Farrar, J. A., 1998) which have shown similar variations in energy transfer among various SPT hammer types.

CASE HISTORIES

Seismic Evaluation of Large Dam, Western Massachusetts

Energy testing was performed on three test borings taken for a liquefaction analysis of an existing dam in Western Massachusetts. The dam was constructed from 1928 to 1932 with a hydraulic fill embankment and riprap cover on the slopes. Two borings, B-4 and B-7, were taken using a truck-mounted rig on a roadway over the top of the dam. One boring, B-5, was taken using a skid rig set upon a wood platform constructed at the edge of the reservoir. Borings B-5 and B-7 were taken with the same drill rig. A second rig was used for B-4. Both rigs were equipped with Diedrich automatic hammers. The subsurface profiles consisted of silts, sands and gravelly sands.

In Boring B-4, tests were conducted at sample depths of 20-22 feet and 100-102 feet. For the shallower sample, the energy transfer to the top of the drill string was measured at 68.5%. For the deeper sample, the energy transfer to the top of the drill string and the energy loss through the drill string were both measured. The energy transfer to the top was measured at 68.1%, and the energy transfer at a depth of 80 feet was measured at 53.5% for an energy loss of 14.6% over the 80 feet of drill rod. The rod consisted on 10 foot lengths of NWJ drill rod.

In Boring B-5, tests were conducted at sample depths of 28-30 feet and 100-102 feet. For the shallower sample, the energy transfer to the top of the drill string was measured at 55.3%.

For the deeper sample, the energy transfers to the top of the drill string, and 80 feet down the drill string were measured. The energy loss through the drill string was calculated as the difference between the two. The energy transfer to the top was measured at 57.4%, and the energy transfer at a depth of 80 feet was measured at 47.8% for an energy loss of 9.6% over the 80 feet of drill rod. The rod consisted on 10 foot lengths of NWJ drill rod.

In Boring B-7, tests were conducted at a sample depth of 33-35 feet. The energy transfer to the top of the drill string was measured at 56.8%, which is very similar to the 55.3% and 57.4% measured previously with the same equipment at B-5. Prior to taking the measurements at B-7, it had been conjectured that the lower energies in B-5, compared to B-4, were due to the B-5 rig operating upon the wood platform where it was visibly bouncing during the SPT testing. Boring B-7 showed that the bouncing of the drill had little, if any, effect on energy transmission.

The reason for the differences in energy transfer between the two rigs may be related to maintenance or simply differences in the machining or fabrication tolerances of the equipment.

Residential Development, Danbury, Connecticut

A total of 46 test borings were taken for a residential condominium development in Danbury, Connecticut. Due to scheduling priorities, four drill rigs including 2 rope and cathead safety hammers and 2 wireline safety hammers were used.

Energy measurements on the wireline safety hammers for this project showed average energy transfers of 40%. Energy measurements on the rope and cathead safety hammers for this project showed average energy transfers of 65%.

The site subsurface profile consisted of existing fill, organic soils, loose to medium dense silty fine sands, glacial till and bedrock. A comparison of field N values, and the corresponding energy corrected N_c values, in the silty fine sands follows:

Depth	N for Safety Rope+Cathead	N for Safety Wireline	N_c
20 - 22 ft.	8	15	9
25 - 27 ft.	11	20	13
30 - 32 ft.	21	29	21

Municipal Structure, Queens, New York

A total of 42 test borings were taken to depths of 100 to 120 feet for a proposed municipal structure. Due to scheduling priorities, a total of five drill rigs were utilized. Three of the rigs used a Mobil wire line safety hammer and two used a rope and cathead safety hammer

Energy measurements on the wireline safety hammers for this project showed average energy transfers of 46%. Energy measurements on the rope and cathead donut hammers for this project showed average energy transfers of 47%.

The site subsurface profile consisted of existing fill and organic soils to depths of 35 to 45 feet; a deposit of outwash sand which varied in thickness from 0 to 50 feet; and the Raritan Clay. A comparison of field N values, and the corresponding energy corrected N_C values, in the outwash sands follows:

Depth	Nfield Donut Rope+Cathead	Nfield Safety Wireline	N_C
45 ft.	36	35	28
50 ft.	32	33	25
55 ft.	36	36	28

Seismic analyses included a liquefaction evaluation of the existing fills, and a lateral load analysis of the pile foundations. The N values were corrected for both overburden and energy transfer for the analyses.

LOCAL BUILDING CODES

The New York City Building (NYC) Code seismic requirements are based on an effective peak acceleration of 0.15 g. In regard to liquefaction, the NYC Code requires that the liquefaction potential of sands and silts be determined on the basis of uncorrected N values in accordance with Figure 1.

The Massachusetts State Building (MSB) Code seismic requirements are based on an effective peak acceleration of 0.12 g. In regard to liquefaction, the MSB Code requires that the potential for liquefaction be evaluated if N values fall below the design lines provided on Figure 2.

The NYC Code specifies that uncorrected N values are to be used, which the writers interpret as referring to overburden corrections and not energy corrections. The MSB does not specify if N values are to be corrected for either energy transfer efficiency or overburden stress.

Building codes in Connecticut, Rhode Island, Vermont, New Hampshire and Maine do not discuss liquefaction analyses. However, the local practice is frequently to perform liquefaction analyses. When ground improvement is required, many performance specifications require that post-treatment N values satisfy the MSB Code criteria.

In Table 1, the range of 31 to 77% corresponds to energy correction factors (Ne) of 0.52 to 1.28. A large error can occur in specifying the MSB Code without regard to energy transfer. To illustrate this, we have created an idealized site where the true (60% energy transfer) N values correspond to a liquefaction factor of safety of unity, using the MSB Code values. For comparison, we have computed the Nfield values that would be obtained using hammers with energy transfers of 31%, 77% and 34%, which are taken from the least efficient hammer, most efficient hammer, and least efficient safety hammer, respectively.

Depth	N for MSB	Nfield E=31%	Nfield E=77%	Nfield E=34%
0 ft.	7	13.5	5.5	12.4
10	8	15.4	6.2	14.1
20	11	21.2	8.6	19.4
30	12	23.1	9.4	21.1
40	13	25.0	10.1	22.9
50	14	26.9	10.9	24.7
60	15	28.8	11.7	26.5

Clearly, an uninitiated engineer could form two strong but very different opinions regarding the liquefaction potential of the idealized site depending on which set of Nfield values was provided, even if he/she prohibited the use of donut hammers.

There are instances where the Code standards shown by Figures 1 and 2 do not provide appropriate guidance to the engineer. For example, those figures are applicable to flat ground, not sloping ground situations. Also, where the Code figures indicate that the apparent factor of safety against liquefaction is less than one, the engineer will commonly resort to a more sophisticated analysis. In the seismic stability against liquefaction analysis of a large dam such as the illustrated case history one, a complex analysis is applicable. For these instances, the conversion from Nfield to Nc will usually involve several other correction factors together with the energy transfer efficiency. One such factor utilizes the energy loss with depth of the drill string following the deep energy transfer efficiency measurements cited for case history one.

CONCLUSIONS

1. For 27 tests presented, the transfer energy efficiency varied from 31 to 77 percent. For the automatic hammers, the rate of drop and the fabrication tolerances are the important variables. For non-automatic hammers the manual operation is the important variable. The following observations, all of which are in general agreement with studies by others, were made.

    a. The CME automatic hammers had the highest efficiency.

    b. The donut hammers lifted with rope and cathead had the lowest efficiency.

    c. The wireline safety hammers had significantly lower efficiencies than the rope and cathead safety hammers.

    d. The wireline safety hammers and the rope and cathead donut hammers had high degrees of variability.

    e. A reduction in drop rate appeared to lower the efficiency of the CME automatic hammers, but not the Diedrich automatic hammers.

2. Energy transfer efficiency corrections are warranted for all projects involving liquefaction analyses. The corrections can have a significant effect for some projects involving static loading analyses.

3. The building codes in the Northeast should be reworded to define the input standard penetration test value to be as corrected for measured transfer energy efficiency.

4. Energy transfer testing is relatively inexpensive with the PDA method. Of particular note is that the delays in drilling time are short.

REFERENCES

Batchelor, C., Goble, G., Berger, J. and Miner, R., "Standard Penetration Test Energy Measurements on the Seattle ASCE Field Testing Program", 1995, ASCE Seattle, Washington Geotechnical Section.

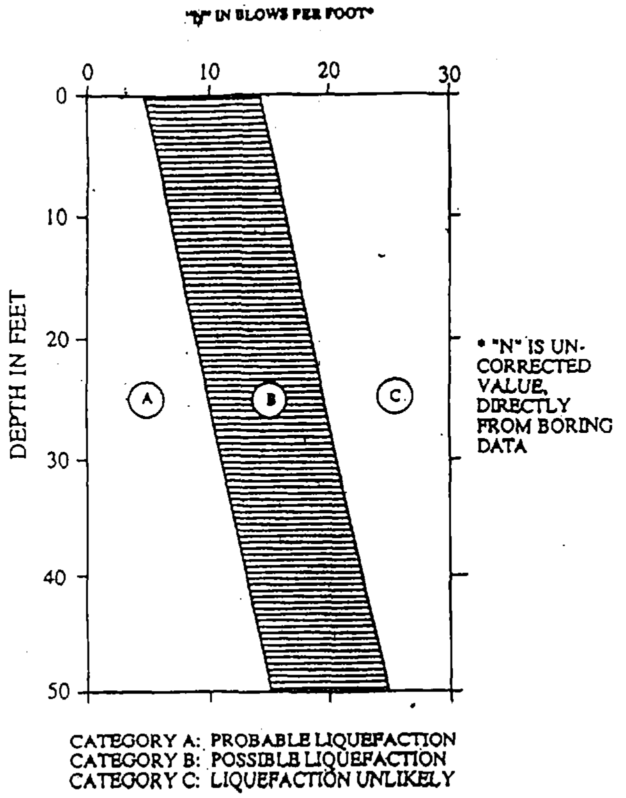
Farrar, J. A., "Summary of Standard Penetration Test (SPT) Energy Measurement Experience", Geotechnical Site Characterization, Robertson & Mayne, editors, 1998, Balkema.

Butler, J. J., Caliendo, J. A., and Goble, G. G., "Comparison of SPT Energy Measurement Methods", Geotechnical Site Characterization, Robertson & Mayne, editors, 1998, Balkema.

Riggs, C., Mathes, G. and Rassieur, C., "A Field Study of an Automatic SPT Hammer System", Geotechnical Testing Journal, ASTM, 1984.

Riggs, C., Schmidt, N., and Rassieur, C., "Reproducible SPT Hammer Impact Force with an Automatic Free Fall SPT Hammer System", Geotechnical Testing Journal, ASTM, 1983.

Ireland, H. O., O. Moretto, and M. Vargas (1970),"The Dynamic Penetration Test: A Standard That is Not Standardized," Geotechnique, Vol. 20, No. 2.



(Reference Standard RS 9-6 added by Local Law 17/1995, eff. 2/21/96.)

(rev.95) X RS 9-12

Figure 1

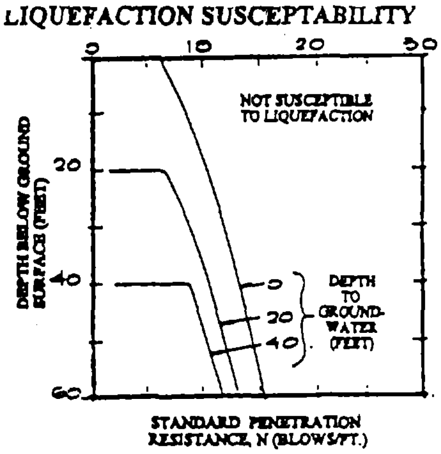


Figure 2

Table 1 – Field Measurements Program

Test No.	Location	Hammer Type	Rod Type	Drop Rate	N Value	Eavg FV	Std. Dev.	Coef. Var.
1	Western MA.	Diedrich Automatic	NWJ	40	18	69	3.7	5.4
1a	Western MA	Diedrich Automatic	NWJ	25	24	68	2.5	3.7
2	Western MA	Diedrich Automatic	NWJ	28	48	55	2.0	3.6
2a	Western MA	Diedrich Automatic	NWJ	42	48	57	2.5	4.4
2b	Western MA	Diedrich Automatic	NWJ	45	43	57	1.2	2.1
3	Stamford, CT	Safety R+C	NW	53	10	63	4.1	6.5
4	Danbury, CT	Safety R+C	AW	61	15	64	6.2	9.7
4a	Danbury, CT	Safety R+C	AW	57	16	66	6.1	10.1
5	Danbury, CT	Safety Wireline	NWJ	50	25	34	2.0	5.9
6	Danbury, CT	Safety Wireline	NWJ	46	46	46	4.1	8.8
7	Poughkeepsie, NY	Safety Wireline	NWJ	53	13	43	1.8	4.2
7a	Poughkeepsie, NY	Safety Wireline	NWJ	50	13	43	2.5	5.9
8	Queens, NY	Safety Wireline	NWJ	50	38	50	3.0	6.0
9	Queens, NY	Safety Wireline	NW	48	40	44	8.7	20.0
9a	Queens, NY	Safety Wireline	NW	51	80	41	4.0	9.8
10	Queens, NY	Donut R+C	N-4	52	29	48	2.3	4.7
10a	Queens, NY	Donut R+C	N-4	57	43	46	3.5	7.7
11	Queens, NY	Donut R+C	N-4	50	37	53	6.0	11.4
11a	Queens, NY	Donut R+C	N-4	61		41	3.4	8.3
12	Wethersfield, CT	CME Automatic	AWJ	55	51	77	3.3	4.3
12a	Wethersfield, CT	CME Automatic	AWJ	38	27	63	2.2	3.4
12b	Wethersfield, CT	CME Automatic	AWJ	55	27	72	2.2	3.0
13	Stamford, CT	Safety Wireline	NWJ	51	49	38	2.7	7.0
14	Bloomfield, CT	Safety Wireline	NWJ	60	17	72	2.8	3.9
15	Hamden, CT	CME Automatic	AW	53	7	69	3.5	5.2
15a	Hamden, CT	CME Automatic	AW	52	28	76	0.8	1.0
16	Providence, RI	Donut R+C	NWJ	45	100+	33	3.3	10.0
16a	Providence, RI	Donut R+C	NWJ	61	106	31	3.5	11.3