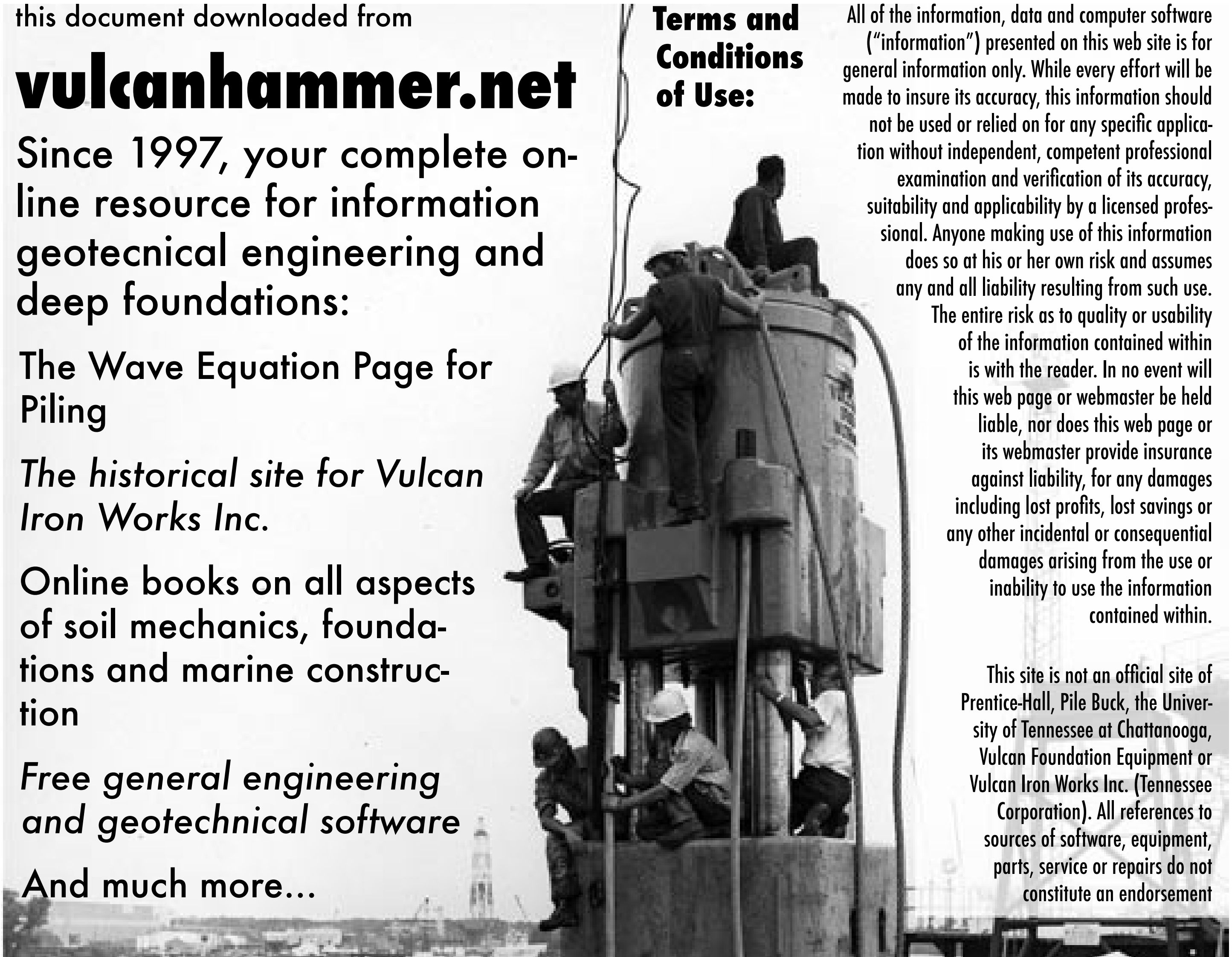

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U.S. Army Corps of Engineers
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Technical Letter
No. 1110-1-138 | 31 March 1988

Engineering and Design
STANDARD PENETRATION TEST

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Engineer Technical
Letter 1110-1-138

31 March 1988

Engineering and Design
STANDARD PENETRATION TEST

1. Purpose. This letter furnishes information and guidance on the conduct of the Standard Penetration Test (SPT), when its penetration values are used in soil liquefaction evaluations.

2. Applicability. This letter is applicable to all HQUSACE/OCE elements and field operating activities (FOA) having military construction and civil works design responsibility.

3. References. See Enclosure 1. Throughout this letter numbers in brackets refer to the numbered items in Enclosure 1.

4. Background. In 1958, the American Society for Testing and Materials (ASTM) first adopted the "Standard Method for Penetration Test and Split-Barrel Sampling of Soils, ASTM D1586 (SPT)". The SPT has been used routinely in subsurface exploration and soil design, with many engineering relationships between SPT N values and other soil design parameters (such as relative density, angle of internal friction, shear strength, bearing capacity, and soil liquefaction potential) having been developed. However, in spite of the seemingly detailed "standard" method specified in ASTM D 1586-84 [1], there still exists many factors (see Enclosure 2 for factors affecting the SPT results [4]) which lead to a wide variation in SPT results for a given soil. This variation, or the low degree of repeatability, has caused difficulties in interpreting SPT results and using historical data with confidence. Recent research, especially in the dynamics of the SPT and the field energy measurement of the SPT hammers, have greatly advanced the knowledge of the SPT and as a result, the variation of the test can be minimized.

5. Discussion.

a. The theoretical SPT energy, E^*, supplied by a 140 lb hammer, falling freely 30 inches, is 4200 in-lb. From field measurements [8], the available energy, E_i, that actually reaches the sampler for doing the work of penetration can vary from 30% to 85% of E^*. The average E_i for the safety hammer and the donut hammer are 61% (ranging from 40% to 78%), and 45% (ranging from 30% to 76%) of E^*, respectively [5]. It has also been shown [8] that SPT N values vary inversely with E_i. Therefore, the N values for a given soil can vary by a factor of about three due to variations in E_i. E_i depends on such factors as the mechanism of the drill rig, the fall height of the hammer, the efficiency of energy transfer at the impact from hammer to anvil, and to the drill rod, the length and type of drill rod, the number of turns of the rope around the cathead, the age of the rope, and the operator. If E_i is measured, the effect of such factors on the SPT can be eliminated or minimized.

b. ASTM D 4633-86, "Standard Test Method for Stress Wave Energy Measurement for Dynamic Penetrometer Testing Systems" [2], specifies the requirements and the use of energy measurement equipment to measure E_i. The theoretical background of the two formulas and their related correction factors utilized by ASTM D 4633-86 can be found in references [3], [8], and [10]. With the loss of energy traveling through the rod being considered negligible for rod lengths less than 100 feet [8], and after applying the correction factors, the energy measured by a load cell located at least ten rod diameters length below the anvil (the hammer impact point) should produce E_i.

c. To date, there have been only eight units of the SPT energy measurement equipment called SPT energy calibrators or simply calibrators [3], built in accordance with ASTM D 4633-86. One of the units is owned by the National Bureau of Standards (NBS) and the remainder are owned by private firms. Presently, Dr. George Goble at the University of Colorado is developing a new version of the SPT energy measurement equipment using the well known pile driving analyzer. The SPT energy calibrator [3], made by Binary Instruments Inc., consists of a strain gage load cell and an instrument box (essentially an analog computer). The load cell, which is located at least ten rod diameters length below the anvil transmits the stress wave (force-time history) by a cable to the instrument box that performs the integration of the force-time history according to the two formulas of ASTM D 4633-86 within the time duration (Δt) of the first compressive wave to obtain energy E_i. The SPT calibrator [5] does not always produce a reliable result due to damage of electronic circuits in the load cell, which causes the calibrator to prematurely cut off the recording of the downward traveling compressive wave resulting in a reduced E_1. Also, a compressive wave returning (sometimes even without a hard driving condition) from the sampler results in an increased E_1. However, these two problems can be detected by checking the time duration of the first compressive wave, Δt, which should be theoretically equal to $2L'/C$, where L' = length of drill rod from load cell to the tip of the sampler, and C = 16,800 ft/sec (the stress wave velocity of the steel drill rod). Any results showing excessive deviation from the value $\Delta t = 2L'/C$ should not be used.

d. The sampler without liners (i.e. having 1.5" inside diameter) would obtain a lower N value of about 10% to 30% than that of a sampler with liners (i.e. having 1-3/8" inside diameter). Schmertmann [7] concluded that removing the liners from a SPT sampler designed for liners improved recovery and removal, but it produced a significant reduction in N and tended to make the SPT more dependent on the sampler end bearing resistance. Seed [9] showed that the percent reduction was about 10% for looser sand and 25% to 30% for denser sand. Drillers in the United States often do not use such liners, while the routine practice of drillers in Japan uses a sampler having an inside diameter of 1-3/8" throughout its length.

6. Action to be Taken. The equipment and procedures used for the standard penetration test should be in general conformance with ASTM D 1586-84. The additional specifications below, with the exception of the method of recording penetration in gravelly materials, are intended to improve the repeatability of the results, and provide results that are comparable to the bulk of the historical data, which are the empirical basis for evaluating liquefaction potential and other important engineering properties by the SPT. It must be emphasized that special care and attention to detail are needed to obtain results of the quality and reliability needed in seismic stability studies. All relevant details of the procedure should be clearly shown on the driller's log.

a. Drive Weight Assembly. To produce results that are comparable to the historical data, the ideal drive assembly should consistently deliver sixty percent of the theoretical free fall energy to the rods [9]. Safety hammers using a rope and cathead with two turns of the rope around the cathead produce an average of approximately sixty percent of the theoretical energy, but the results can vary depending on the operator and other factors as mentioned in paragraph 5a. Automatic hammers that permit nearly a free fall can produce more consistent results with proper setup and adjustments, but generally deliver more energy to the rods. The best results can be obtained by using an automatic hammer with a known energy output. When the data is analyzed, the results can be corrected to the standard sixty percent energy with the following relationship.

$$N_{60} = N_m \cdot \frac{ER_i}{60}$$

Where $ER_i = E_i/E^*$ is measured energy ratio for the drill rig and hammer system used, N_m = blowcounts measured with E_i, and N_{60} = blowcounts corrected to 60% energy ratio. Improvements to the hammer or changes in the operating procedure can change the results in an unknown way, and should be avoided unless the hammer will be recalibrated. For soil liquefaction analyses, the energy E_i of the drill rig and the hammer to be used for the project should be measured with a SPT energy calibrator. Limited and changing sources for SPT energy calibration are available, and the FOA should contact HQUSACE, CEEC-EG when such calibration is needed for equipment operated by the Corps of Engineers, or specified for use by contractors.

b. Rod. Type NW rods should generally be used and the type of rods should be recorded. Because the correction to the blowcount is required for short rod lengths [3], [8], [10], the length of rod should also be recorded for each drive where the rod length is less than 45 feet. The current practice [9] for correcting the reduced E_i for short rod lengths is by multiplying the measured N values, made within the hole depth of less than 10 feet, by a factor of 0.75. Alternately, the measured N values can be divided by the K_2 values listed in ASTM D 4633-86 to obtain the corrected N values. The threaded couplings in the rods should be snug. Generally, grease should be used to aid in breaking the rods, but string or other energy absorbing materials should not be used in the joints.

c. Sampler. A sampler with a straight inner wall having an inside diameter of 1-3/8 inches should be used. If the sampler has provisions for a liner, it should be used with a liner in place. This practice would be comparable to the condition under which the bulk of the historical data was obtained.

d. Blowcount Rate. The blowcount rate should generally be 20 to 40 blows per minute. If it is necessary to use a slower rate (see paragraph 6i) that fact should be carefully noted in the log.

e. Drilling Mud. A bentonite base drilling mud should be used to support the hole and to prevent heave of the bottom of the hole. The mud column must also be above the level needed to balance artesian pressures that may be encountered. Care should be taken to insure that a safe mud level is maintained while the sample is being withdrawn.

f. Hole Diameter. To provide lateral support for the drill rod the hole should be kept to a diameter of five inches maximum. Where casing is used, it should be of four inch inside diameter and the casing should be kept as far as possible away from the test interval.

g. Advancing the Hole. To minimize disturbance, the hole should be cleaned out to a depth of about one foot below the previous drive. This permits one test in each 2-1/2 foot interval. The method of rotary drilling with side discharge bits and drilling mud should be used to advance the hole with special precautions required so that the material below the bottom of the hole is not disturbed. Tricone roller bits have been used successfully. Fishtail or drag bits should have baffles that divert the flow of the drilling fluid upwards.

h. Samples. Generally, it will be necessary to perform a sieve analysis on each sample and possibly a hydrometer analysis and/or determine Atterberg limits. Therefore, as much of the sample should be saved as feasible, after the contaminated material at the top of the sample tube is discarded. More than one jar sample may be required to be saved in some cases.

i. Gravelly Sands. In granular soils containing occasional pieces of gravel, the method of recording should be modified. The modified procedure is to measure and record, to the nearest 1/4 inch, the cumulative penetration after each blow. However, if the penetration per blow is less than about 1/2 inch the measurement may be made after every other blow or less frequently, so long as at least one measurement is recorded for each inch of penetration. For each measurement, record the cumulative number of blows and the cumulative penetration. The results should be presented on a plot of cumulative penetration versus cumulative blowcount. Using the slope of this curve, an estimate can frequently be made of what the blowcount would have been without the influence of gravel.

7. Implementation. This letter will have routine application as defined in paragraph 6c, ER 1110-345-100.

FOR THE COMMANDER:

2 Encls
as

HERBERT H. KENNON
Chief, Engineering Division
Directorate of Engineering and Construction

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Factors Affecting the Results of the SPT

After Fletcher, 1965, Marcuson et al. 1977, and Schmertmann, 1977

Test Detail	Effect on N-value	Estimated Percent by Which Cause Can Change N
Inadequate cleaning of disturbed materials in the borehole	Decreases	
Failure to maintain sufficient hydrostatic head in the borehole	Decreases	100%
Variations from the exact 762 mm (30 in) drop	Either	± 10%
Length of drill rods	Increases	
< 3 m (10 ft)		50%
10 to 16 m (30 to 80 ft)		0
> 30 m (100 ft)		10%
Any interference with free fall (using 2 to 3 turns)	Increases	to 100%
Using deformed sample spoon	Increases	
Excessive driving of sample spoon before the blow count	Decreases	
Failure of driller to completely release the tension of the rope	Increases	
Driving sample spoon above the bottom of the casing	Increases	
Use of wire line rather than manila rope	Increases	
Carelessness in recording blow count	Either	
Insufficient lubrication of the sheave	Increases	
Larger size of borehole	Decreases	50%
Penetration interval		
N_0 to 12 in instead N_6 to 18 in	Decreases	15% sands 30% insensitive clays
N_{12} to 24 in versus N_6 to 18 in	Decreases	15% sands 30% insensitive clays
Use of drilling mud versus casing in water	Increases	100%
Large vs small anvil	Increases	50%
Use of A rods versus NW rods	Either	± 10%
Larger ID for liners, but no liners	Decreases	10% sands 30% insensitive clays