NBSIR 84-2910

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FIELD EVALUATION OF SPT ENERGY, EQUIPMENT, AND METHODS IN JAPAN COMPARED WITH THE SPT IN THE UNITED STATES

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PREFACE

The study presented in this report was initiated, planned, and executed as a joint research program within the purview of the U.S.-Japan Panel on Wind and Seismic Effects.

A Standard Penetration Test (SPT) program was carried out in Japan over a one month period beginning October 16, 1983. Participation of the field work included personnel from the National Bureau of Standards and the Bureau of Reclamation on the U.S. Side and the Public Works Research Institute of the Ministry of Construction and OYO Corporation on the Japanese Side.

This report contains the following information as a result of the study: a) U.S. and Japanese practices on the Standard Penetration Test, b) comparison of U.S. SPT and Japanese SPT test results, and c) comment on SPT liquefaction design curves with respect to the Japanese data base.

A number of organizations and individuals contributed to the success of this study. Funding for this study was provided by the National Bureau of Standards, the Bureau of Reclamation, the National Science Foundation, the Naval Facilities Engineering Command, and the Waterways Experiment Station. The joint program coordination and support in Japan were provided by Dr. T. Iwasaki and Mr. Y. Sasaki of the Public Works Research Institute, and Dr. K. Suyama and Mr. Ohya of OYO Corporation. Their contributions are greatly appreciated.

ABSTRACT

Field energy measurements on Japanese drill rigs were made during the performance of the Standard Penetration Test to document the difference between Japanese and present U.S. practice. A total of 78 Standard Penetration Tests were performed using 19 different testing conditions (equipment and operators). Over 2,200 data points are reported.

Results from this investigation show less scatter than U.S. data and the average value for ER_i (the ratio of the energy passing through the drill rod to the theoretical free-fall energy) using Japanese equipment and operators is 68 percent with a standard deviation of 9.6 percent. Considering only energy and sampler effects, the ratio of U.S. blow counts to Japanese blow counts (N_{US}/N_J) is 0.98 (variation between 0.72 and 1.80) when the cathead and rope method was used as the hammer release mechanism and using ER_{US} equals 55 percent and ER_j equal to 67.4 percent. When the Tombi method (free-fall) was used, the ratio of N_{US}/N_J is 1.17 (variation between 0.86 to 2.15) when ER_{US} equals 55 percent and ER_j equals 80.4 percent. It was found that the Japanese use bottom discharge drill bits and an SPT sampler with a constant inside diameter of 1-3/8 in (35 mm) in contrast to U.S. procedures and equipment. A shape factor to account for differences in sampler is presented.

Keywords: Energy measurement, field testing, in situ testing, liquefaction potential, soil mechanics, SPT, Standard Penetration Test.

EXECUTIVE SUMMARY

Field energy measurements were made in Japan during the performance of the Standard Penetration Test (SPT) (ASTM D 1586) to document how the Standard Penetration Test is performed and used in present Japanese engineering practice and to compare the Japanese SPT results with those found in the United States. The field studies were conducted over a 1 month period beginning October 16, 1983, at three Japanese locations. The first location, north of Akita, consisted of three separate drilling sites in which the potential energy, the kinetic energy at impact, and the energy transmitted through the drill rods were measured during the Standard Penetration Test. Both the American Society for Testing and Materials (ASTM) and the Japanese Industrial Standard (JIS) samplers were used. At the second location at Niigata, tests similar to those in Akita, were performed in three borings. Two sites in an earthquake area that liquefied and one site in an area that did not liquefy were chosen for the in situ tests at Akita and Niigata. Nine additional sites in the Tokyo-Yokohama area were also selected to obtain a better representation of the performance of drill rigs used in Japan. At the three locations, a total of 78 individual Standard Penetration Tests were performed using 19 different testing conditions (equipment and operators) with approximately 2,215 individual data points.

The primary energy measuring system which measured the energy passing through the drill rod consisted of an SPT Energy Calibrator, integration timer, oscilloscope, and a load cell that was mounted in the drill rod at least 10 drill rod diameters below the point of hammer impact. The secondary energy measurement system which measured the potential and kinetic energy of the hammer consisted of a black and white target mounted on the SPT hammer, light beam scanners that record the passage of the hammer during its rise and fall, and the signal conditioning required for the scanners. Two tape recorders were also used to record information from the Calibrator and to provide a permanent record of the force-time curve, integration time, and output from the top and bottom scanners.

The Japanese drill rig equipment consisted of either a wooden or a steel tripod placed over a portable drilling machine used to perform wash borings. A rotary wash drilling method utilizing a bottom discharge bit and drilling mud was used to advance the hole.

The Standard Penetration Test in Japan is performed in accordance with the Japanese Industrial Standard (JIS) A 1219-1961 (reaffirmed 1978). This standard fixes the size of the SPT sampler to a 2 in (51 mm) outside diameter and an inside diameter of 1-3/8 in (35 mm) throughout its length. Anvils (knocking heads) 3 inches in height and diameter are also required. A 1.6 in (40.5 mm) drill rod was used throughout the testing program. Either the cathead and rope method or the Tombi method (free-fall) was used as the hammer release mechanism. The catheads on the Japanese rigs typically ranged in length from 3 to 6 inches (75 to 150 mm) and many of them had curved surfaces with maximum diameters approximately 8 in (203 mm) and with minimum diameters of approximately 4.3 in (109 mm). Cathead speeds varied between 60 and 300 rpm, depending on the operator.

Results from this investigation are presented in terms of the ratio of the energy passing through the drill rod during the first compression wave pulse to the theoretical free-fall energy assuming a 762 mm (30 in) fall (ER_i). Comparing the range of ER_i values in Japan with those of the United States, one finds that the Japanese data exhibit less scatter than the U.S. data. The average value for ER_i using Japanese tests is 68 percent with a standard deviation of 9.6 percent. This figure includes energy ratio results using the cathead and rope and the Tombi method as the hammer release method. If the data for each of the hammer release mechanisms are treated separately, the average results for ER_i for the cathead and rope and the Tombi method are 67 percent and 80 percent, respectively. The average value for ER_i using data from U.S. tests is approximately 55 percent which includes all published cathead and rope data with the ASTM sampler without liner.

The number of turns of rope around the cathead and rope age had little effect on ER_i in Japan in contrast to U.S. experience. The effect of sampler type on the standard penetration resistance, N, was found to be significant. On the average blow count values (N_J) obtained using the JIS sampler were found to be approximately 25 percent greater than blow count values obtained using the ASTM sampler.

For the cathead and rope method, and considering only energy and sampler effects, the ratio of U.S. blow counts to Japanese blow counts (N_{US}/N_J) is 0.98 (with a variation of 0.72 to 1.80) considering the energy and samplers used, and the average values of U.S. and Japanese energy of 55 and 68 percent, respectively. When the Tombi method was used, the ratio of N_{US}/N_J was 1.17 (with a variation between 0.86 and 2.15. Because of this variability in the ratio of N_{US}/N_J, it would be prudent to reexamine the design curves used to evaluate liquefaction potential considering this variation.

This study also showed Japanese practice produces a rate of blow application only about 1/3 that in U.S. practice. The Japanese also use drilling mud and bottom discharge methods to advance the hole, which the ASTM has successfully prohibited in U.S. practice. These effects, and perhaps others not yet identified, may have significant importance and remain not studied to date.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

NOTATION

E_i = Energy passing through the drill rod as measured from the first compression wave pulse.

E^* = The standard potential energy specified for the Standard Penetration Test (SPT), 4200 in-lbs (475 J).

e_1 = E_v/E^*, the efficiency of the rope hammer pulley system which depends on the number of turns of rope around the cathead, rope age, drill rig geometry, and probably other factors not specifically identified that may include cathead speed and diameter and operator characteristics.

e_2 = E_i/E_v, the efficiency of the hammer-anvil system in transferring energy to the drill rod; also known as the energy transfer ratio, ETR.

E_v = The kinetic energy of the hammer just before impact.

ER_i = Ratio of the energy passing through the drill rods observed from the first compression wave pulse to the theoretical free-fall energy assuming a 30 in (762 mm) fall.

ER_J = Energy ratio in Japan.

ER_{US} = Energy ratio in the U.S.

N = SPT blow count or penetration resistance in blows per foot over a 6 to 18 in (15 to 45 cm) penetration interval.

N_{cj} = Blow count using the cathead and rope method in Japan.

N_{tj} = Blow count using the trip monkey (Tombi method) in Japan.

N_{cf} = N-value using cathead and rope method outside of Japan.

N_J = SPT blow count or penetration resistance in blows per foot obtained using Japanese operators, equipment, and procedures.

N_{US} = SPT blow count or penetration resistance in blows per foot obtained using U.S. operators, equipment, and procedures.

N_{68} = SPT blow count normalized to an energy ratio (ER_i) of 68 percent.

S = Sampler shape factor.

S_J = Japanese sampler shape factor.

S_{US} = U.S. sampler shape factor.

1. INTRODUCTION

Field energy measurements on Japanese drill rigs were made during the performance of the Standard Penetration Test (SPT) (ASTM D-1586). The field studies were conducted in Japan over a 1 month period beginning October 16, 1983. The measurements were taken at three different general locations. The first location, north of Akita, consisted of three separate drilling sites in which data on the hammer potential energy, the hammer kinetic energy at impact, and the energy passing through the drill rods were collected during the Standard Penetration Test, using the ASTM and Japanese Industrial Standard (JIS A1219-1961) samplers. Two sites in an area that liquefied during the 1983 Northern Japan Earthquake and one site in an area that did not liquefy were chosen for the in situ tests at Akita. A total of 958 data points (blow counts) were obtained at the Akita sites using three types of SPT hammers typically used in Japanese engineering practice.

The second location was at Niigata and it was tested in a similar manner with three borings. Two borings were in an area that liquefied and one boring was in an area that did not liquefy. In Niigata extensive liquefaction occurred throughout the city during the 1964 earthquake. By performing Standard Penetration Tests at known liquefaction and nonliquefaction sites, as in previously documented studies, the SPT energy on which present liquefaction potential design procedures are based can be estimated. A total of 639 data points were obtained at the Niigata sites.

Nine additional sites in the Tokyo-Yokohama area were also selected to obtain a better representation of drill rigs used in Japan. Six hundred eighteen (618) data points were obtained in the Tokyo-Yokohama area.

A total of 78 individual Standard Pentration Tests were performed using 19 different testing conditions (equipment and operators) with approximately 2,215 individual data points being reported.

1.1 PURPOSE

The purposes of this study are: 1) document how the Standard Penetration Test is performed and used in present Japanese engineering practice, 2) compare the Japanese SPT results with those found in the United States, and 3) comment on the SPT liquefaction design curves with respect to the Japanese data base.

1.2 SCOPE

The energy in the drill stem of Japanese SPT equipment was measured using ASTM and JIS samplers. This information was used to compare U.S. and Japanese blow counts.

1.3 BACKGROUND

Traditionally, the blow count, N, obtained from the Standard Penetration Test has been a major tool in the evaluation of liquefaction potential or cyclic mobility of sandy sites. Available Japanese SPT data form an important part of the information base that was used to develop the SPT design curves to evaluate liquefaction potential (Seed et al., 1983). There is evidence that the SPT results obtained in Japanese practice differ from those in U.S. practice. Kovacs et al. (1983) have shown that variations in the energy passing through the drill rod constitute a major problem in U.S. SPT practice. The energy is affected not only by the hammer release mechanism, operating procedure, and operator characteristics, but also by the type of hammer and anvil used. Thus, it is necessary to reference the design curves used in liquefaction studies to a specific energy level. Japanese SPT practice as specified in Japanese Industrial Standard (JIS) A 1219 differs from U.S. practice and there is a difference between the U.S. and Japanese sampler. Thus, it is also necessary to estimate a correlation between U.S. and Japanese practice and to ascertain whether Japanese data points were accurately considered when the design curves were established. It will then be possible to calibrate the rigs used in field exploration on safety-related projects and, if necessary, correct the blow count to account for the difference between the energy level assumed in the design curves and that obtained in the field.

Schmertmann and Palacios (1979) concluded that the energy reaching the sampler, E_i, is inversely proportional to the blow count, N. Hence, the energy passing through the drill rod that reaches the sampler must be known to compare blow counts.

The energy passing through the drill rod in the SPT can be expressed by the following equation:

$$E_i = E^* \cdot e_1 \cdot e_2 \tag{1}$$

where E_i = energy passing through the drill rod,

E^* = the standard potential energy specified for the SPT = 4200 in-lbs (475 J),

$e_1 = E_v/E^*$, the efficiency of the rope hammer pulley system which depends on the number of turns of rope around the cathead, rope age, drill rig geometry, and probably other factors not specifically identified that may include cathead speed and diameter, and operator characteristics,

$e_2 = E_i/E_v$, the efficiency of the hammer-anvil system in transferring energy to the drill rod; also known as the energy transfer ratio, ETR,

E_v = the kinetic energy of the hammer just before impact;

The efficiency of the rope/hammer/pulley system has been estimated to average approximately 68 percent ($e_1 = 0.68$) in typical U.S. practice (Kovacs et al., 1981, 1983). The Japanese practice of throwing the rope off the cathead should result in an increase in the velocity of the falling hammer just before impact as compared to present U.S. practice where the rope is not thrown off. It was initially estimated that the energy loss in Japanese practice is no more than one-half the energy loss in U.S. practice. This would produce a kinetic energy at hammer impact of 84 percent of the standard energy ($e_1 = 0.84$).

Recent field tests have shown that the Japanese type SPT donut hammer is more efficient than the U.S. safety hammer. On March 7 and 8, 1983, Purdue University, in collaboration with the National Bureau of Standards (NBS), conducted field tests on a variety of SPT hammers which included a donut (type) hammer and anvil (knocking head) machined according to the dimensions of the Japanese SPT Standard (Japanese Industrial Standard, JIS A 1219-1961, reaffirmed: 1978), and which were dropped by free fall to eliminate the variable e_1 ($e_1 = 1.0$). In addition, the drill rod specified in JIS A 1219 [1.6 in OD (40.5 mm)] was approximated by using AW rods [1.75 in OD (44.5 mm OD)]. In accordance with these tests, the average of 10 drops of the Japanese donut hammer produced an e_2 of 0.76 with a coefficient of variation of 3.5 percent. This compares with an estimated average for e_2 of 0.65 for all U.S. hammers published to date (Kovacs et al., 1983),

It appeared from this information, that in typical Japanese practice using donut type hammers, $e_1 \cdot e_2 = 0.64$, while in U.S. practice $e_1 \cdot e_2$ on the average is only 0.44 (Kovacs et al., 1983). Including safety hammers, the efficiency of U.S. rigs was found by Kovacs et al. (1983) to average approximately 0.55, which is still less than the efficiency of Japanese equipment. This difference between U.S. and Japanese equipment and procedures is significant and must be considered when liquefaction data are interpreted.

Tokimatsu and Yoshimi (1983) have shown statistically that the SPT N-value by the cathead and rope method in Japan is greater by about 20 percent than the trip monkey (free-fall) or Tombi method for any N-values up to about 40. Thus, they proposed the following relation for converting blow counts from one method to blow counts for the other method.

$$N_{cj} = 1.2\ N_{tj} \qquad (2)$$

where cj means cathead and rope method in Japan, and tj means trip monkey in Japan.

Tokimatsu and Yoshimi also proposed a relationship for interpreting the SPT N-values from other countries besides Japan according to eq. (3).

$$N_{cf} = 1.4\ N_{tj} \qquad (3)$$

where cf means cathead and rope method in other countries.

Another source of difference is the sampling spoon used. Equation (3) did not take into account the effects of sampler shape. SPT samplers used in the U.S. are constructed in accordance with ASTM D 1586 and have an inside diameter of 1-3/8 in (35 mm) for the cutting shoe and an inside diameter of 1-1/2 in (38 mm) for the barrel. The 1/16 in (1.6 mm) recess in the barrel is for a liner, which in most instances is not used in current practice. Without the liner, the friction is reduced. According to Schmertmann (1979, 1980), this could account for a 10 to 30 percent reduction in N values in sands. Japanese samplers do not have the recess for liners. When comparing U.S. and Japanese rigs, an additional correction will have to be made to account for the difference in sampler configuration. The correction for the sampler will be discussed later.

2. EQUIPMENT USED IN THE STUDY

2.1 DRILL RIG EQUIPMENT

The Japanese drill rig equipment consisted of either a wooden or steel tripod placed over a portable drilling machine used to perform wash borings. These drill rigs have the capacity to drill to approximately 300 ft (91 m). Figure 1 shows a typical tripod over a portable drilling machine performing Standard Penetration Tests. The catheads on these rigs normally range in length from 3 to 6 in (76 to 152 mm) and many of them have curved surfaces with maximum diameters approximately 8 in (203 mm) with minimum diameters of approximately 4.3 in (109 mm). Typically, the cathead speed varies between 60 and 300 rpm, depending on the operator. Figure 2 illustrates two typical drill tools with hardened steel cutting edges and open bottom discharge bit. The hole is advanced using a driller and an assistant operator.

2.2 SPT EQUIPMENT

The Standard Penetration Test in Japan is generally performed in accordance with Japanese Industrial Standard (JIS) A1219-1961 (reaffirmed 1978). This standard fixes the size of the SPT sampler to a 2 in (51 mm) outside diameter and an inside diameter of 1-3/8 in (35 mm) throughout its length. In addition to the JIS sampler, an ASTM sampler was used in 28 of the Standard Penetration Tests. Typical drill rod sizes have been surveyed by Yoshimi and Tokimatsu (1983). For this study, a 1.6 in (40.5 mm) drill rod was used throughout the testing program. The cross-sectional area assumed for the drill rod is 0.827 sq in (534 sq mm) (Tsuneaki Iwasaki, private communication, October 18, 1983). The U.S. AW drill rod is 1.75 in (44.5 mm) OD by comparison.

Several types of cylindrical, i.e., donut-shaped hammers were used during the study. A typical donut hammer is shown in the top of figure 1. The hammers are assumed to be 140 lbs (63.5 kg) and vary in height from 10-1/2 in (267 mm) to 13-3/4 in (349 mm). The outside diameter of the hammers varied from 7 to 8 in (178 to 203 mm) while the inside diameter of the hole varied from 1.6 to 2.0 in (40.5 to 51 mm). The truncated cone hammers which were used three times were approximately 16 in (406 mm) in height and varied from 6 to 8 in (152 to 203 mm) in top and bottom outside diameters, respectively, with a 2 in (51 mm) inside diameter hole. In some cases, a reinforcing bar was welded to the eyelets and inclined at a 45 degree angle from the horizontal for attachment of the cathead rope. The remaining hammers used had chains to operate the hammer as a falling weight during the test.

The anvil used in the performance of the SPT differs substantially from typical practice in the United States where a more massive piece of steel is used. Anvils varied from 3 to 3.5 in (76 to 89 mm) in diameter and from 2.1 to 3.4 in (53 to 86 mm) in height. The Japanese Industrial Standard A1219 requires a height of 3 in (76 mm) and a diameter of 3 in (76 mm).

2.3 ENERGY MEASUREMENT EQUIPMENT

The primary energy measuring system consisted of the SPT Energy Calibrator, integration timer, and an oscilloscope (figure 3). The Calibrator measures ER_i, the ratio of the energy passing through the drill rods observed from the first compressive wave pulse to the theoretical free fall energy assuming a 30 in (762 mm) fall, expressed as a percentage. Not shown in figure 3 is the load cell that connects into the SPT Calibrator and which is mounted in the drill rod at least 10 drill rod diameters below the point of impact. A further description of the SPT Calibrator is given by Hall (1982) and Kovacs et al. (1983). The timer is connected electrically to the oscilloscope output of the SPT Calibrator to provide a digital readout of the integration time. The integration time should approximate the return time for the compressive wave to pass through the load cell and return as a reflective tensile wave from the bottom of the sampler. A second connection from the SPT Calibrator goes to the oscilloscope where the wave form and the integration time may be monitored visually.

The secondary energy measurement system (e.g., Kovacs et al., 1983) consisted of a black and white target mounted on the SPT hammer, the light beam scanners which record the passage of the hammer during its rise and fall and the signal conditioning required for the scanners. Two tape recorders were also used to record information from the Calibrator readout devices and to provide a permanent record of the force-time curve, integration time, and output from the top and bottom scanners. Figure 1 shows the bottom scanner, that is mounted exactly 30 in (762 mm) from the top scanner (not shown), attached to a piece of lumber adjacent to the hammer during the performance of the SPT.

Figure 1. Tripod over portable drilling machine used in Japan for performing the SPT

Figure 2. Two drilling tools with hardened steel cutting edges and the open bottom discharge bit

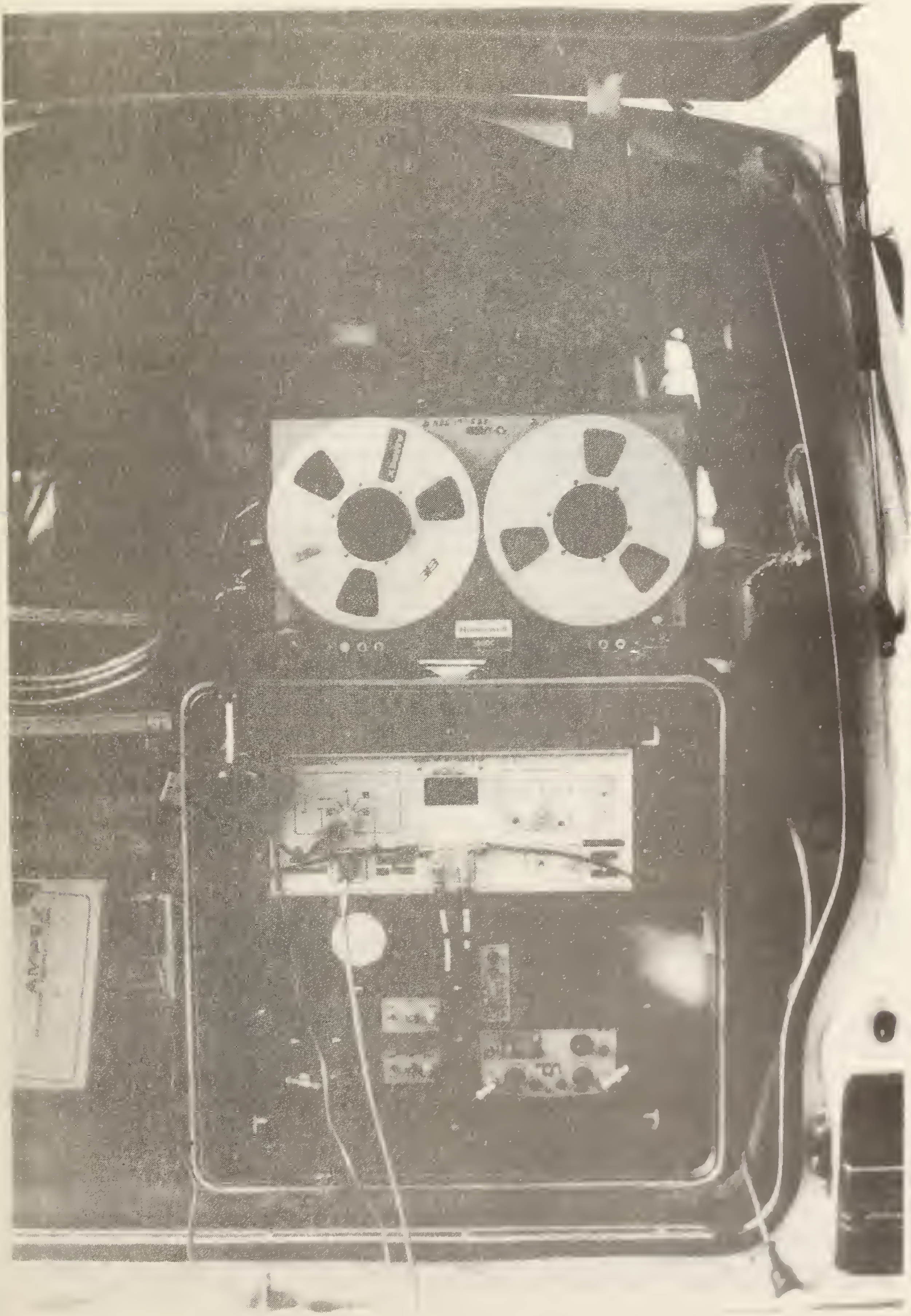

Figure 3. Energy measurement equipment in field shock proof case: SPT Calibrator, timer, and oscilloscope

3. PROCEDURES

3.1 DRILLING PROCEDURES

A rotary wash drilling method utilizing a bottom discharge bit and drilling mud was used to advance the hole. A steel casing 4 in (10.2 cm) in inside diameter was frequently driven to seal off the upper layers and provide a non-erodable outlet for the drilling mud. Below the cased hole the diameter of the uncased hole was approximately 2.5 in (6.5 cm). The drillers estimated that the rate of flow of the drilling fluid through the bottom discharge bit to be approximately 8 to 11 gallons per minute (30 to 40 liters per minute). When the desired depth to perform the SPT test was obtained, the drill rig operator assured that the hole was cleaned out, the pump shut off, and the drill rods withdrawn. Generally the drilling procedures followed during this study were those described by Hvorslev (1949) and by the Department of Interior, Bureau of Reclamation (1974) except that a bottom discharge bit was used. However, it should be pointed out that the fluid level was not maintained when the drill rods were withdrawn. This practice and the use of bottom discharge bits could result in lower blow counts. Parsons (1966) noted that the fluid level is not often maintained in the U.S. either.

3.2 SPT PROCEDURES

With the drill hole cleaned out, and the rods withdrawn, an SPT sampler was connected to the bottom of the drill stem and reinserted into the boring to the desired depth. A check was made to ensure that the bottom of the sampler was within 2.4 in (60 mm) of the bottom of the hole. Generally, the Standard Penetration Test was run with the rods inside the rotating kelly of the drill rig. However, in some instances, it was impossible to install a load cell and allow sufficient penetration of the sampler because of interference with the drill rig. Consequently, it was necessary to perform the SPT with the kelly removed from over the drill hole.

On many of the drill rigs, the operator had the choice of a top or bottom cathead. In the cases tested and observed in Japan, the rotation of the cathead was such that the top of the cathead rotated toward the operator and as a result, the number of turns was generally less than the nominal turns by 1/4 of a turn. For example, many operators used 3/4 of a turn and 1-3/4 of a turn to perform the SPT. On certain occasions, operators made an effort to throw the rope completely off the cathead during the downstroke of the hammer. Because of these procedures, the rate of testing was from 7 to 25 blows per minute with an average of approximately 15 blows per minute, substantially less than that of American practice of 30 to 60 blows per minute. The slower rate of performing the SPT was due to the method of rope release as well as the drill rig operators' desire to provide a fall height as close to the required 30 in (762 m) fall as possible. Many of the operators used what is termed the "hold-drop" procedure wherein the operator raises the hammer until the bottom of the hammer is just at the 30 in (762 mm) mark above the anvil and then releases the rope as quickly as possible. The operators were extremely careful to obtain the required drop height before quickly releasing the hammer. The above procedure was used with the cathead and rope approach. For some tests the Tombi method was used wherein either type of hammer (donut shaped or truncated cone shaped hammer) was released by a metal hook. This procedure allowed essentially free-fall of the hammer independent of the drill rig and operator.

The operator counted the number of blows that the sampler penetrated every 6 in (150 mm) for a total of 18 in (450 mm). A further count was made of the number of blows to advance an additional 2 in (50 mm). The Standard Penetration Test blow count or N-value was then taken as the sum of the penetrations between 6 and 18 in (150 and 450 mm) as specified in JIS A 1219 and ASTM D1586 procedures.

The JIS sampler with its constant 1-3/8 in (35 mm) inside diameter was used alternatively with the ASTM sampler with its 1-3/8 in (35 mm) inside diameter shoe and 1-1/2 in (38 mm) inside diameter split barrel to evaluate the effect of sampler shape on energy and SPT N-value results. The use of alternate sampling in adjacent borings permitted the comparison of blow counts essentially at the same level with approximately the same energy. The effect of sampler shape on blow counts could then be evaluated.

3.3 ENERGY MEASUREMENT PROCEDURES

The procedures used to measure the potential and kinetic energy of the hammer and the energy passing through the drill rods have been documented in previous reports (Kovacs et al., 1975, 1981, and 1983). They are briefly summarized below for convenience.

Preparation

Fasten a target of black and white strips 1/8 in (3.2 mm) in width around the hammer.

Insert the load cell in the drill rod and attach the anvil to the top of the load cell.

Connect the SPT Calibrator to the timer, oscilloscope, and tape recorder and position the light beam scanners on the scanner holding rod and clamp it in the testing position.

Perform the three-stage calibration of the Calibrator as prescribed by the manufacturer's instruction manual with the hammer at rest on top of the anvil.

Testing

Start the tape recorders and begin the Standard Penetration Test.

Read the parameter ER_i, the energy ratio to the nearest whole number, expressed as a percentage of the SPT energy of 4,200 in-lbs (475 J); then after the blow, read the peak force from the calibrator. During the test, the timer was read and all of the information was recorded on a hand-held tape recorder for tabulation. Also, a multichannel tape recorder was used to record the scanner output, the load cell output and the timer output for future analyses, as required. The oscilloscope displayed the shape of the stress wave after each blow and the duration of the integration time. Reset the Calibrator for the next blow.

3.4 DATA REDUCTION PROCEDURES

The average energy ratio, ER_i, was evaluated in the field after each Standard Penetration Test was completed. The energy ratio, ER_i and the integration time that was recorded on the hand-held tape recorder were tabulated in the field. The corrections K_1, K_2, and K_c which account for the fact that the load cell is not positioned at the point of impact (K_1), the drill rods are not infinite in length (K_2), and the actual compressive wave velocity in the steel rods and couplings is different than the theoretical value built into the Calibrator's energy ratio computation (K_c), were also computed. These corrections have been discussed by Hall, (1982) and Kovacs et al. (1983). Standard Penetration Test results are provided in section 5.

4. DRILLING AND TESTING SITES

4.1 INTRODUCTION

Standard Penetration Test data were obtained at Akita, Niigata, Tokyo, and Yokohama, Japan. The locations are shown in figure 4 as sites A through L. Sites were selected where liquefaction occurred and where liquefaction did not occur to obtain a variation in blow counts and soil conditions. Sites A through C were chosen in the Akita area because of the May 26, 1983 earthquake. The city of Niigata (sites D through F) was chosen specifically for comparison with the historical field SPT studies that were performed following the 1964 Niigata earthquake. The Tokyo/Yokohama sites (G through L) were used to obtain more information on Japanese operator characteristics and equipment under different or additional soil conditions and thus obtain a better statistical sample of the energy ratios and SPT practice for Japan.

4.2 AKITA SITES

Figure 5 illustrates the guide map of Akita showing sites A, B, and C in the Hachiro-Gata area. In addition to sites A, B, and C, a fourth site known as Boring FD 7+415 was found during the course of testing in which a truncated cone was tested using both cathead and rope and the Tombi methods. Seven borings over the four sites yielded 958 data points in areas that liquefied and those that did not liquefy during the May 26, 1983 earthquake. Figure 6 illustrates the bore hole testing arrangement at sites A, B, and C in which six other types of in situ tests were performed.

4.3 NIIGATA SITES

Figure 7 shows a guide map of the Niigata area showing sites D, E, and F. Figure 8 illustrates the boring and testing arrangements for the three sites at Niigata. Three sites were chosen in Niigata in which two of them had borings in which the energy was monitored in the drill rods. These were sites D at Kawagishi-cho and site F at the Showa-Ohashi bridge sites. Due to load cell fatigue problems (4 out of 5 load cells failed), only a minimal amount of testing was completed after sites D1 and D2 were evaluated. As a result, site E testing was performed without energy measurements. Three borings in Niigata resulted in a total of 638 data points. The same operator performed borings D1 and F1 while a second operator performed the investigations at borings D2 and E1.

Figure 9 shows a detailed drawing of the Kawagishi-cho sites in which eight apartment buildings exhibited significant movement during the 1964 earthquake. Note that the present study location of borings D1 and D2 were adjacent to a previous study by Ishihara and Koga (1981). The close proximity of these two studies will permit a comparison of blow counts obtained and an estimate of the energy used in previous SPT studies at Niigata.

4.4 TOKYO SITES

A total of nine borings were conducted at six sites (G through L) in the Tokyo area resulting in 618 data points (figure 10). In the Tokyo area, the JIS sampler was driven using a donut-shaped hammer and the cathead and rope or the Tombi method of release.

Figure 4. SPT study region in Japan. Sites A through L (from OYO Corp.)

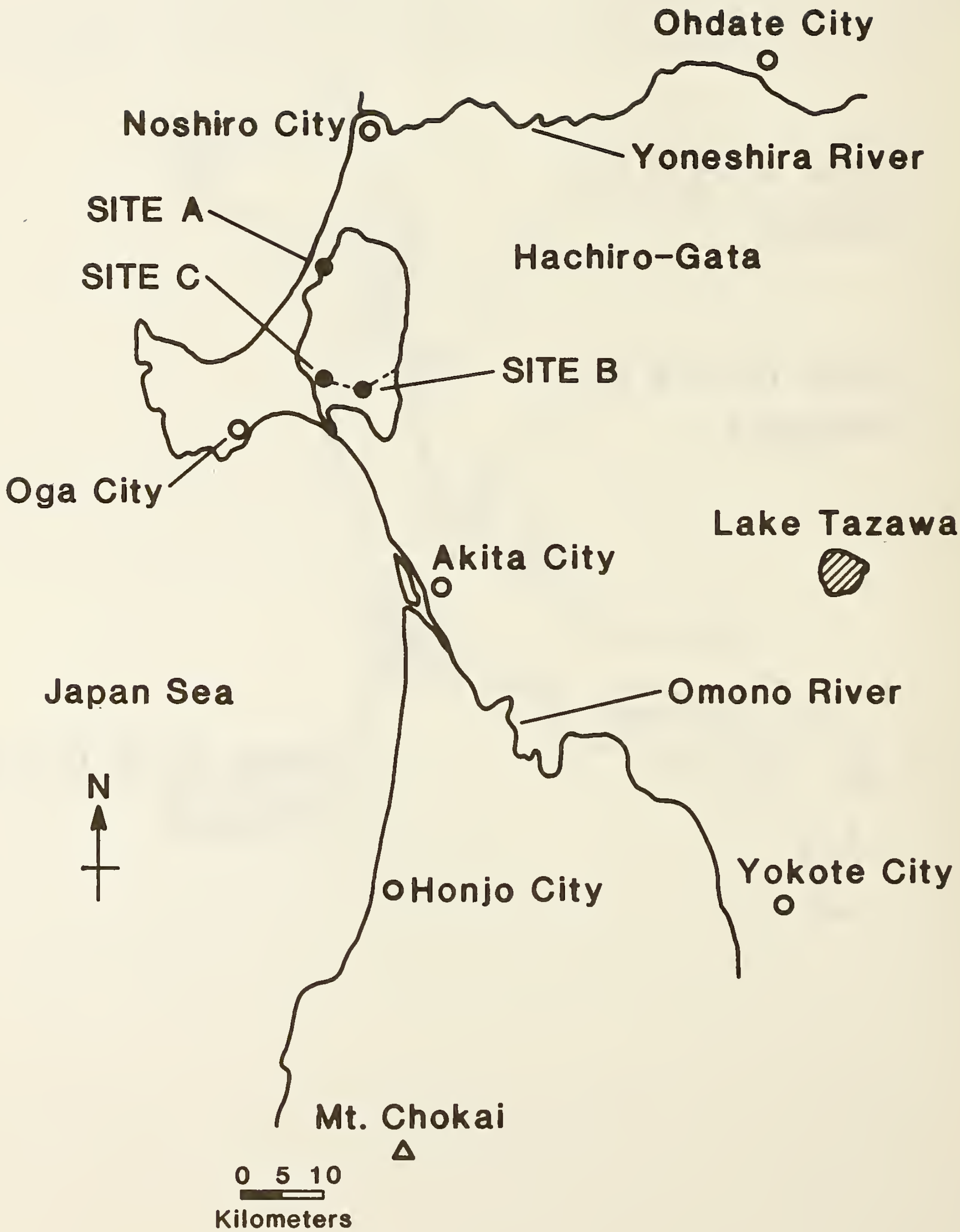

Figure 5. Guide map of the Akita area (from OYO Corp.)

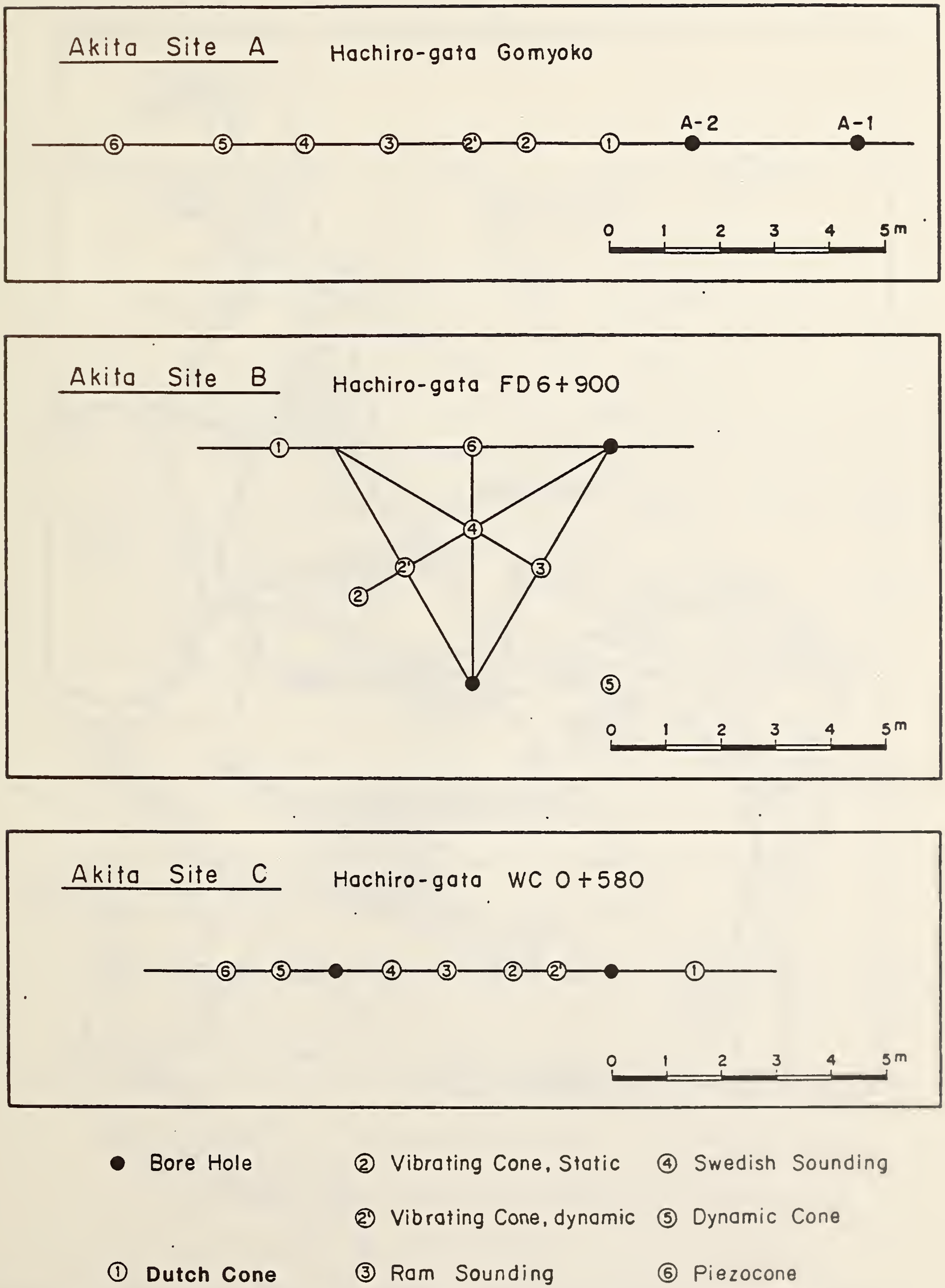

Figure 6. Bore hole testing arrangement at the Akita sites (from OYO Corp.)

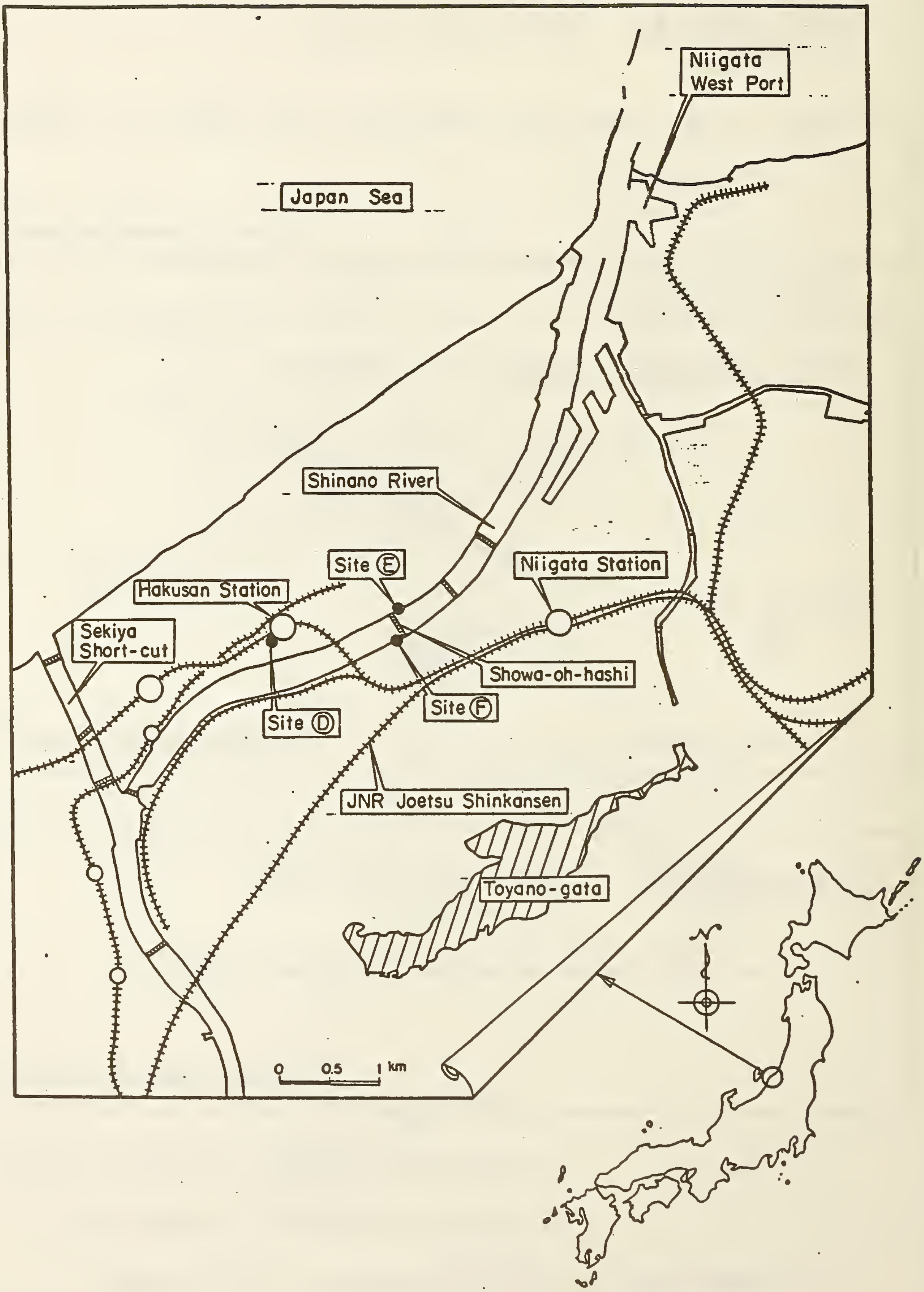

Figure 7. Guide map of the Niigata area (from OYO Corp.)

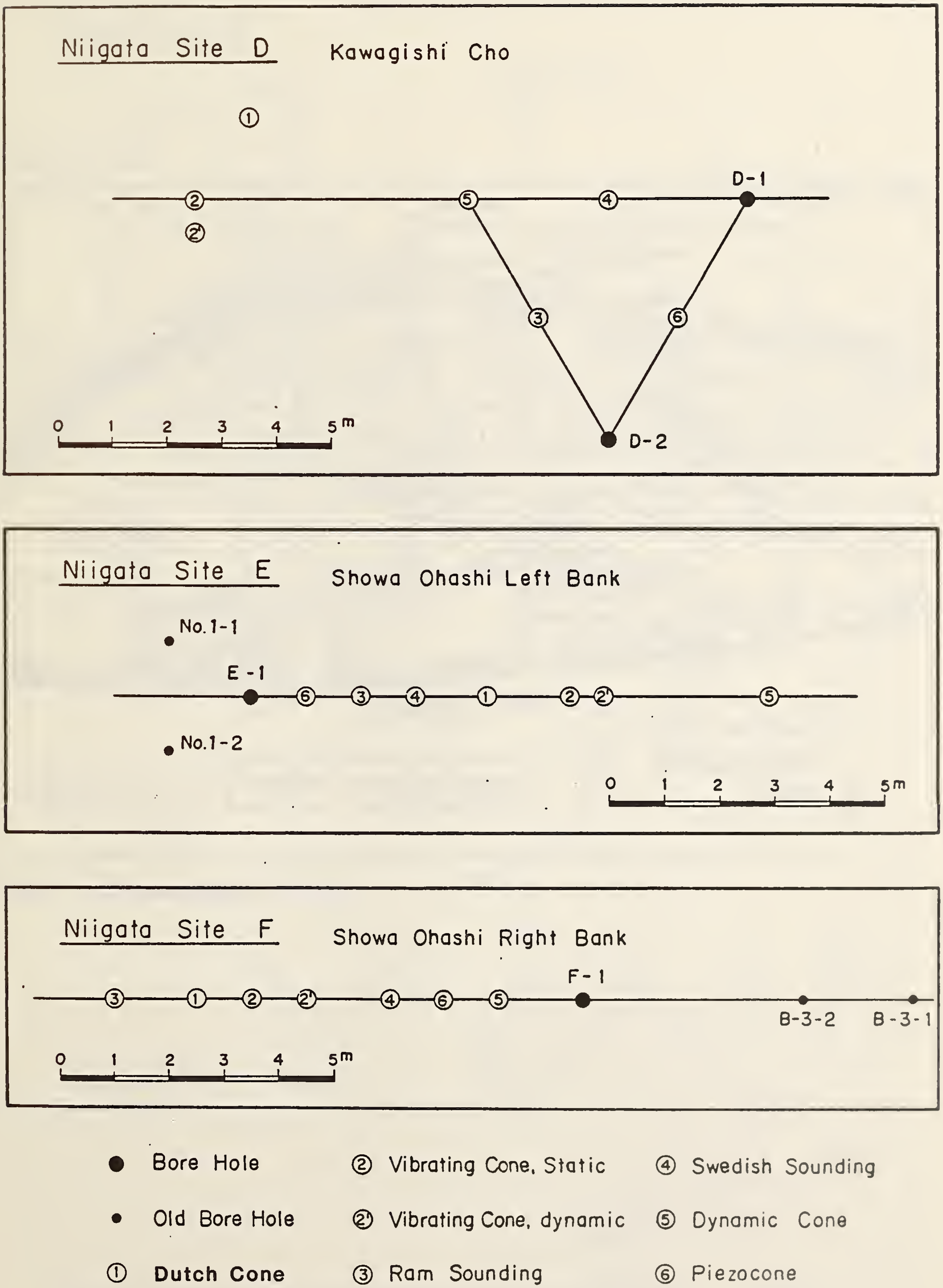

Figure 8. Bore hole testing arrangement at the Niigata sites (from OYO Corp.)

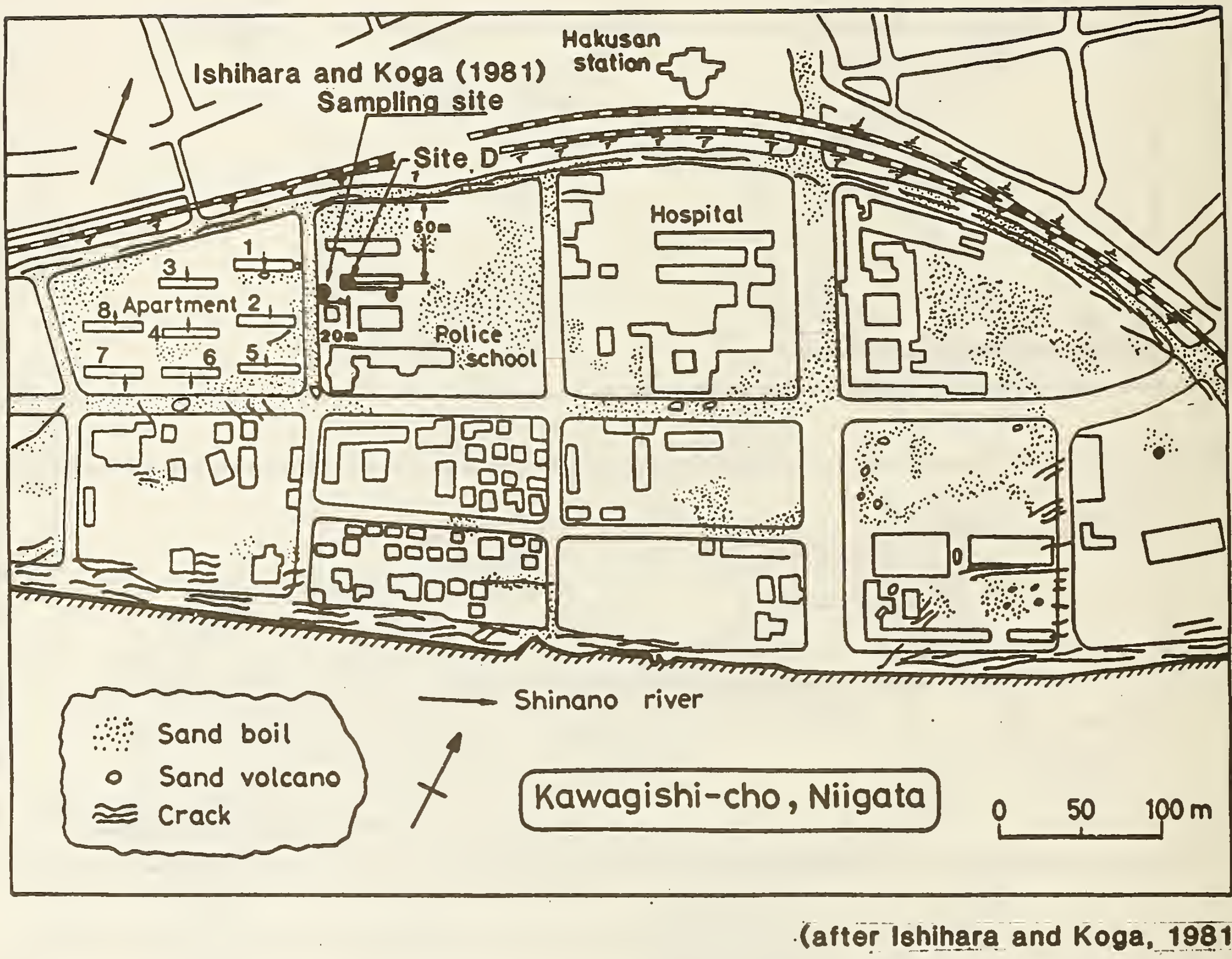

Figure 9. Detailed Map of the Kawagishi-cho site in Niigata (after Ishihara and Koga, 1981)

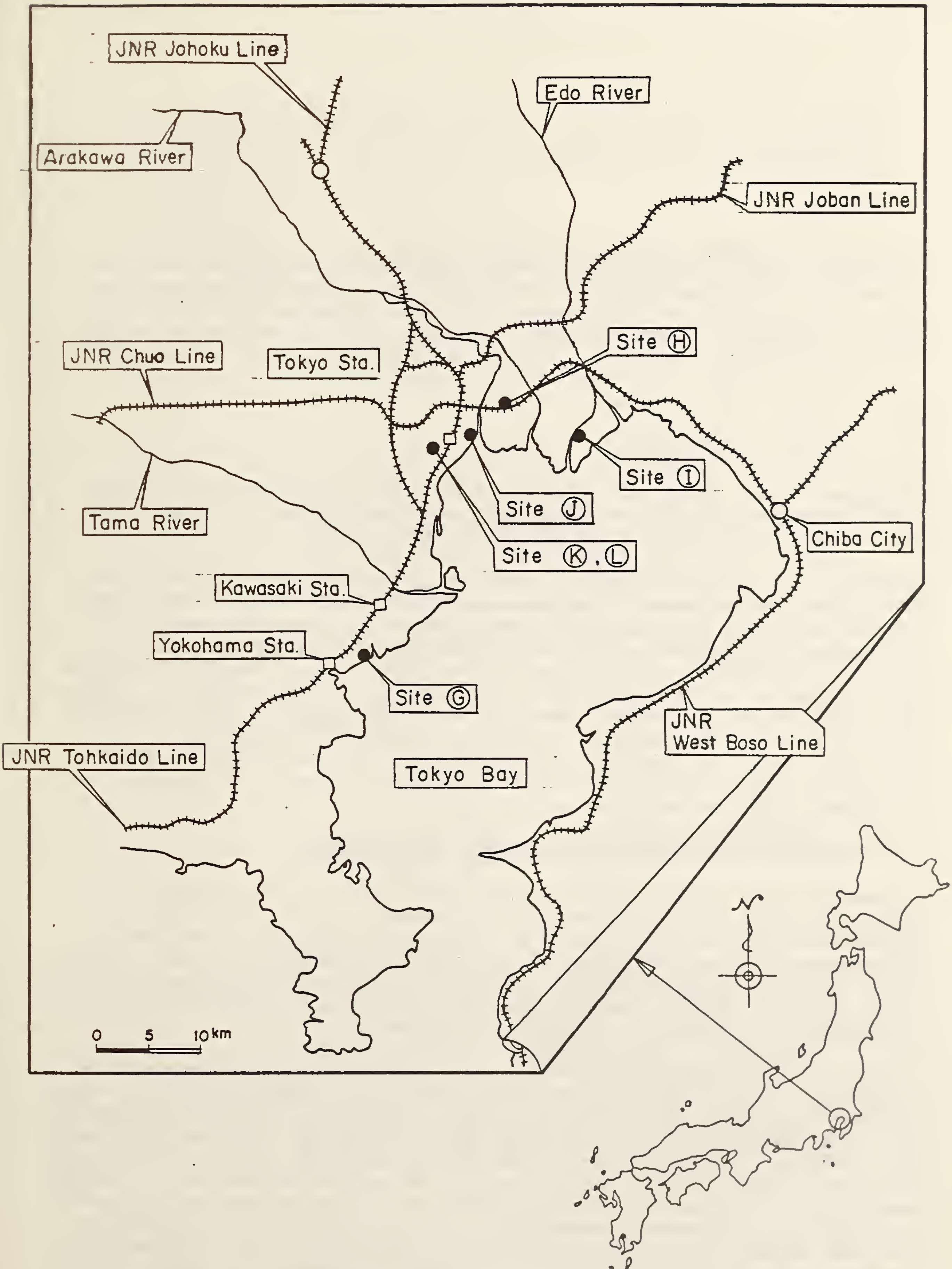

Figure 10. Guide map of the Tokyo area (from OYO Corp.)

5. SPT RESULTS

5.1 GENERAL

A total of 19 borings were made at 12 sites, and 78 individual Standard Penetration Tests were performed using 19 different operators and conditions. Of the 78 tests, 28 were performed using the ASTM sampler and the remaining 50 were performed using the JIS sampler. When the cathead and rope method was used as the hammer release mechanism, the number of turns of rope around the cathead varied as follows:

a. 14 tests -- 3/4 of a turn
b. 51 tests -- 1-3/4 turns
c. 8 tests -- 2-3/4 turns

These results are consistent with the recent survey by Yoshimi and Tokumatsu (1983) in which a nominal two turns were used a majority of the time. Five tests were also performed using the Tombi method.

Table 1 presents a tabulation of the results and test conditions for the 78 series performed in Japan. With the exception of the first two series (144 and 145 which were performed with a wooden guide pipe above the anvil) all the tests were performed using a steel guide pipe during the performance of the SPT. The Energy Ratio, N-value, boring number, nominal depth, the sampler type, and number of turns used by the operators are listed in table 1. Further, the dimensions of the cathead hammer and anvil used are summarized. Finally, the rate at which the operators performed the Standard Penetration Tests in blows per minute are given in the last column. To better appreciate the significance of these various test results, a graphical summary is presented and discussed in the next section.

5.2 PRESENTATION OF ENERGY RATIO RESULTS, ER_i (PERCENT)

A summary of the energy ratio data versus blow count for the operators using cathead and rope or the Tombi method is presented in figure 11. Figure 11 demonstrates that the energy ratio is independent of blow count as found by Schmertmann (1978) and Robertson et al. (1983). Comparing the range of energy ratio values in Japan from figure 11 with those of the United States as given by Kovacs et al. (1983), one finds that the Japanese data exhibits less scatter than data from present U.S. engineering practice.

Figure 12, a frequency diagram of the data, indicates that the average is 68 percent with a standard deviation of 9.6 percent and a coefficient of variation of about 14 percent. Data for U.S. practice averages approximately 55 percent with a standard deviation of 12 percent and a coefficient variation of 22 percent. Figure 12 includes energy ratio results using the cathead and rope and the Tombi methods. If the data for each of the release mechanisms are treated separately the average for the Tombi method and for the cathead and rope method would be 80 and 67 percent respectively. The ratio of the energy ratios for the Tombi method and the cathead and rope method (80/67) equals 1.19 which compares favorably with the ratio of 1.2 given by Tokimatsu and Yoshimi (1983).

To better appreciate how the energy ratio varies with operator, figure 13 has been prepared in which the individual operators and their averages and sample standard deviations (given in parentheses) are shown graphically with respect to the average of all data. The small capital T beside five of the data points represents the Tombi method was used.

Figure 14, illustrates the effect of the blow count and the number of rope turns around the cathead during the performance of the SPT. The Tombi method data have been excluded from figure 14. Figure 14 shows little effect of the blow count as well as the number of turns of rope around the cathead. In figure 15, ER_i is plotted directly with the number of turns of rope used around the cathead. The trend is contrary to what has been found in U.S. practice where the energy ratio decreased with an increasing number of turns especially after three turns were used around the cathead.

The difference in rope age is plotted on figure 16 for 1-3/4 turns of rope. Figure 16 shows no appreciable difference in energy as a function of rope age. Again, this is contrary to U.S. practice where older rope gives a lower energy ratio. Two reasons may be cited as to why the number of turns of rope and rope age did not have an effect on the average energy ratio in the drill rods. First, a much smaller cathead diameter and rope diameter is used in Japan as compared to U.S. practice (Yoshimi and Tokimatsu (1983) and Table 1). Secondly, Japanese drill rig operators make a determined effort to throw the rope off of the cathead during the down stroke. Thus, the number of turns of rope recorded before each blow may not truly be the actual number of turns during the fall of the hammer.

5.3 PRESENTATION OF ER_i VERSUS DEPTH

5.3.1 Introduction

The figures in this section illustrate not only how N varies with depth because of differences in soil layers but illustrates the energy variation within a given Standard Penetration Test profile with depth and the effects of the two different types of samplers that were used.

5.3.2 Akita Sites

Figures 17a, b, and c illustrate the N-value profile with depth for borings A1 and A2, B1 and B2, and C1 and C2, respectively. In figure 17, the circled data point was obtained using the JIS sampler while the triangular symbol is used to designate the ASTM sampler data. The numbers in parentheses adjacent to the data points are the average value of the energy ratio in the drill stem, ER_i. A solid line connects the data points for a given boring. If one were to normalize the profile of N-value versus depth to a constant energy ratio of 68 percent ($N_{68} = N \cdot ER_i/68$) (based on figure 12) then the data for each boring would be represented by the dashed lines on figures 17a, 17b, and 17c.

5.3.3 Niigata Sites

In a similar manner, graphs have been prepared for the two sites in the Niigata area. Figures 18a and 18b illustrate boring D1 and D2, respectively for the Kawagishi-cho site. The symbols mentioned previously for figure 17 are also used in these and following graphs. Note that in boring D1 the energy measurements did not take place until a nominal depth of 11 meters. Both borings D1 and D2 were in a liquefied site. In figure 19 a similar profile of N-value versus depth is shown based on a previous study by Ishihara and Koga (1981). In figure 20, all three graphs (figures 18a and b and figure 19) have been replotted without the data points for the raw data on figure 20. Figure 20 shows reasonable agreement between the N-value profile with the exception of depths between 15 and 18 meters.

In another part of the city on the left bank of the Showa bridge site, boring E1 was completed to a depth of 20 meters without any energy evaluation, Figure 21. Thus, it was not possible to normalize the N-value profile to an energy ratio of 68 percent. Note the low blow counts of approximately 10 blows per foot up to a depth of about 12 meters. Iwasaki et al., 1978, present data shown in figure 22 from the Showa bridge site number 2 where liquefaction occurred. The blow count profiles for figures 21 and 22 are similar to a depth of approximately 12 meters.

Across the river in a nonliquefied site, boring F1 was drilled to a depth of approximately 15 meters. Five Energy Ratio measurements were made thus permitting normalization of a portion of the N-value depth curve to a 68 percent energy ratio. Figure 23 gives an example of the increase in blow count found using the JIS sampler as compared to using the ASTM sampler. Figure 24 illustrates another N-value profile curve in a nonliquefied site at the Showa bridge number 4 boring given by Iwasaki et al., 1978. The blow counts between 2 and 4 meters are similar to those shown in figure 23 and increase with depth up to 12 meters.

5.3.4 Effect of Sampler Type on N-value

The Japanese and the Europeans have faithfully followed ASTM D 1586 since its inception with regard to the physical dimensions of the SPT sampler. The Japanese Industrial Standard A 1219 is based on the present (1984) version of ASTM D 1586. In the United States, those in engineering practice utilizing the SPT have declined to use the brass liner that is available from the manufacturers in the United States for perhaps as long as 10 years. The probable reason for not using a liner in the U.S. sampler with a 1-1/2 in (38 mm) inside diameter barrel is the ease with which the soil sample can be examined and removed from the sampler after each test. Even though the ASTM test method calls for a uniform 1-3/8 in (35 mm) inside diameter split barrel it is now accepted practice in the U.S. to ignore this requirement and it appears that only about 5 percent of the orders for SPT samplers request the liner (Acker Drill Co. and Sprague & Henwood, Inc., 1984, private communication).

From the previous graphs in section 5.3, it is possible to compare the N-value results at a given depth using a JIS sampler and an ASTM sampler to study the effect of sampler type. Table 2 and figure 25 presents the results of this comparison. The N-values have been normalized for a 68 percent energy ratio. Three of the data points have been rejected in figure 25 because they involved very abrupt changes in N-values. Thus, with the exception of one data point, all of the remaining 14 data points lie below the one-to-one line indicating that at the same depth, the JIS sampler resulted in greater N-values than the ASTM sampler.

Schmertmann, in his review of this report, suggested that additional points could be obtained comparing N_{US} with N_J by interpolating data on figures 17 through 19 and 21 and 23. When all the data points are plotted together, figure 26 results. Figure 26 includes data where blow counts have been normalized to 68 percent (50 points) as well as data points where energy ratios have not been measured (29 points). The resulting equations from regression analyses performed using data from figures 25 and 26 are given in table 3.

The question of which sampler shape factor relationship between N_{US} and N_J to use may be answered by a review of table 3. The differences among the six equations are minor from an engineering point of view. For simplicity, we are recommending that the sampler shape relationship of $N_{US} = 0.78\ N_J$ be used, which when rounded off is:

$$N_{US} = 0.8\ N_J, \text{ for constant energy} \qquad (5.1)$$

Note the blow counts are obtained at the same energy ratio.

Table 1
Tabulation of Results and Test Conditions
Steel Guide Pipe Unless Mentioned
Rotary Wash w/MUD and Casing

Series	ER_1 (%)	N (B/ft)	Boring	Depth (m)	Sampler	Turns	Remarks	Operators	Cathead L (in)	Cathead OD (in)	Cathead ID (in)	Cathead RPM	Hammer H (in)	Hammer OD (in)	Hammer ID (in)	Knocking Head OD (in)	Knocking Head H (in)	Rate (B/min)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
144	67	11	B-2	12	A	1 3/4	Wood guide pipe, new 3/4 in rope	A	5	6	5	167	13.75	7.5	2	3	3	10
145	68	4	B-2	13	J	1 3/4	Wood guide pipe, hold drop procedure (HDP)	A	5	6	5	167	13.75	7.5	2	3	3	11.2
146	64	3	B-2	15	A	1 3/4		A	5	6	5	55	13.75	7.5	2	3	3	10.7
147	70	2	B-2	16	J	1 3/4		A	5	6	5	55	13.75	7.5	2	3	3	9.6
148	65	3	B-2	17	A	1 3/4	(HDP)	A	5	6	5	55	13.75	7.5	2	3	3	11.7
149	68	P	B-2	18	J	1 3/4		A	5	6	5	55	13.75	7.5	2	3	3	--
150	65	3	B-2	20	A	1 3/4	(HDP)	A	5	6	5	---	13.75	7.5	2	3	3	7.7
151	70	10	B-1	11	J	1 3/4	(HDP); old, 3/4 in rope	E	5	6.5	5	176	13.75	7.0	1.75	3	2.5	15
152	78	10	B-1	12	A	1 3/4		E	5	6.5	5	176	13.75	7.0	1.75	3	2.5	15.6
153	73	10	B-1	13	J	1 3/4		E	5	6.5	5	176	13.75	7.0	1.75	3	2.5	16.8
154	84	5	B-1	14	A	1 3/4		E	5	6.5	5	176	13.75	7.0	1.75	3	2.5	13.7
155	73	9	FD 7+415	56	J	1 3/4	Truncated cone, new 3/4 in rope	F	5	6.5	5	307	16.0	6, 7.9	2	3	3.4	--
156	84	8	FD 7+415	58	J	TOMBI	Truncated cone	F	5	6.5	5	---	16.0	6, 7.9	2	3	3.4	--

A indicates ASTM sampler (without liner).
J indicates JIS sampler.

Table 1
Tabulation of Results and Test Conditions
Steel Guide Pipe Unless Mentioned
Rotary Wash w/MUD and Casing

Series	ER_i (%)	N (B/ft)	Boring	Depth (m)	Sampler	Turns	Remarks	Operators	Cathead L (in)	Cathead OD (in)	Cathead ID (in)	Cathead RPM	Hammer H (in)	Hammer OD (in)	Hammer ID (in)	Knocking Head OD (in)	Knocking Head H (in)	Rate (B/min)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
144	67	11	B-2	12	A	1 3/4	Wood guide pipe, new 3/4 in rope	A	5	6	5	167	13.75	7.5	2	3	3	10
145	68	4	B-2	13	J	1 3/4	Wood guide pipe, hold drop procedure (HDP)	A	5	6	5	167	13.75	7.5	2	3	3	11.2
146	64	3	B-2	15	A	1 3/4		A	5	6	5	55	13.75	7.5	2	3	3	10.7
147	70	2	B-2	16	J	1 3/4		A	5	6	5	55	13.75	7.5	2	3	3	9.6
148	65	3	B-2	17	A	1 3/4	(HDP)	A	5	6	5	55	13.75	7.5	2	3	3	11.7
149	68	P	B-2	18	J	1 3/4		A	5	6	5	55	13.75	7.5	2	3	3	--
150	65	3	B-2	20	A	1 3/4	(HDP)	A	5	6	5	---	13.75	7.5	2	3	3	7.7
151	70	10	B-1	11	J	1 3/4	(HDP); old, 3/4 in rope	E	5	6.5	5	176	13.75	7.0	1.75	3	2.5	15
152	78	10	B-1	12	A	1 3/4		E	5	6.5	5	176	13.75	7.0	1.75	3	2.5	15.6
153	73	10	B-1	13	J	1 3/4		E	5	6.5	5	176	13.75	7.0	1.75	3	2.5	16.8
154	84	5	B-1	14	A	1 3/4		E	5	6.5	5	176	13.75	7.0	1.75	3	2.5	13.7
155	73	9	FD 7+415	56	J	1 3/4	Truncated cone, new 3/4 in rope	F	5	6.5	5	307	16.0	6, 7.9	2	3	3.4	--
156	84	8	FD 7+415	58	J	TOMBI	Truncated cone	F	5	6.5	5	---	16.0	6, 7.9	2	3	3.4	--

Table 1 (Continued)

Series	ER_1 (%)	N (B/ft)	Boring	Depth (m)	Sampler	Turns	Remarks	Operators	Cathead				Hammer			Knocking Head		Rate
									L (in)	OD (in)	ID (in)	RPM	H (in)	OD (in)	ID (in)	OD (in)	H (in)	(B/min)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
157	61	18	C-2	11	A	2 3/4	Old 1/2 in. rope	C	-	6.5	6.5	304	13.0	7.25	2.25	3.5	2.5	--
158	70	37	C-2	12	J	2 3/4		C	-	6.5	6.5	304	13.0	7.25	2.25	3.5	2.5	--
159	72	33	C-2	15	A	2 3/4		C	-	6.5	6.5	304	13.0	7.25	2.25	3.5	2.5	--
160	69	44	C-2	16	J	2 3/4	Rope wet	C	-	6.5	6.5	280	13.0	7.25	2.25	3.5	2.5	--
161	68	30	C-2	17	A	2 3/4	Rope wet	C	-	6.5	6.5	280	13.0	7.25	2.25	3.5	2.5	--
162	74	30	C-2	18	J	2 3/4	Rope wet	C	-	6.5	6.5	280	13.0	7.25	2.25	3.5	2.5	--
163	77	16	C-2	19	A	2 3/4	Rope wet	C	-	6.5	6.5	280	13.0	7.25	2.25	3.5	2.5	--
164	75	24	C-2	20	J	1 3/4	Rope wet	C	-	6.5	6.5	280	13.0	7.25	2.25	3.5	2.5	--
165	70	25	C-1	11	J	1 3/4	New 3/4 in. wet rope	A	5	6.5	5	161	13.2	7.5	2.0	3	3.4	--
166	69	33	C-1	12	A	1 3/4	New 3/4 in. wet rope	A	5	6.5	5	161	13.2	7.5	2.0	3	3.4	--
167	74	35	C-1	15	J	1 3/4	New 3/4 in. wet rope	A	5	6.5	5	161	13.2	7.5	2.0	3	3.4	--
168	69	26	C-1	16	A	1 3/4	(HDP); rope thrown completely off cathead	A	5	6.5	5	---	13.2	7.5	2.0	3	3.4	--
169	71	17	C-1	17	J	1 3/4		A	5	6.5	5	---	13.2	7.5	2.0	3	3.4	--
170	70	22	C-1	18	A	1 3/4		A	5	6.5	5	178	13.2	7.5	2.0	3	3.4	--

Table 1 (Continued)

Series	ER_i (%)	N (B/ft)	Boring	Depth (m)	Sampler	Turns	Remarks	Operators	Cathead L (in)	Cathead OD (in)	Cathead ID (in)	Cathead RPM	Hammer H (in)	Hammer OD (in)	Hammer ID (in)	Knocking Head OD (in)	Knocking Head H (in)	Rate (B/min)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
171	77	20	C-1	19	J	1 3/4		A	5	6.5	5	178	13.2	7.5	2.0	3	3.4	--
172	75	23	C-1	20	A	1 3/4		A	5	6.5	5	178	13.2	7.5	2.0	3	3.4	--
173	70	37	A-2	11	A	1 3/4	Old 3/4 in. rope thrown completely off cathead	B	-	---	5	224	13.5	7.0	---	3	2.4	--
174	67	15	A-2	12	J	1 3/4	Old 3/4 in. rope thrown completely off cathead; very deliberate	B	-	---	5	224	13.5	7.0	---	3	2.4	--
175	74	4	A-2	13	A	1 3/4		B	-	---	5	224	13.5	7.0	---	3	2.4	--
176	68	5	A-2	14	J	1 3/4	Old 3/4 in. rope thrown completely off cathead; very deliberate	B	-	---	5	238	13.5	7.0	---	3	2.4	--
177	67	7	A-2	19	A	1 3/4	(HDP)	B	-	---	5	---	13.5	7.0	---	3	2.4	7.1
178	74	44	A-2	20	J	1 3/4	(HDP); very deliberate	B	-	---	5	---	13.5	7.0	---	3	2.4	8.3
179	60	59	A-1	11	J	1 3/4	(HDP); very deliberate; old 1/2 in. rope	C	-	6	5	255	13	7.5	2.0	3.4	2.5	18.6
180	66	29	A-1	12	A	1 3/4		C	-	6	5	300	13	7.5	2.0	3.4	2.5	21.5
181	60	6	A-1	13	J	1 3/4		C	-	6	5	---	13	7.5	2.0	3.4	2.5	15.7
182	59	8	D-1	11	J	3/4	(HDP); new, 3/4 in. (white) rope	D	5.8	6.5	4.8	---	11.0	7.6	1.8	3	2.1	--
183	63	7	D-1	12	A	3/4	(HDP); rope thrown off cathead	D	5.8	6.5	4.8	---	11.0	7.6	1.8	3	2.1	--
184	64	9	D-1	14	A	3/4	(HDP)	D	5.8	6.5	4.8	---	11.0	7.6	1.8	3	2.1	--

Table 1 (Continued)

Series	ER_i (%)	N (B/ft)	Boring	Depth (m)	Sampler	Turns	Remarks	Operators	Cathead				Hammer			Knocking Head		Rate
									L (in)	OD (in)	ID (in)	RPM	H (in)	OD (in)	ID (in)	OD (in)	H (in)	(B/min)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
185	66	17	D-1	15	J	3/4	(HDP)	D	5.8	6.5	4.8	---	11.0	7.6	1.8	3	2.1	11.5
186	63	16	D-1	16	A	3/4		D	5.8	6.5	4.8	---	11.0	7.6	1.8	3	2.1	--
187	62	26	D-1	17.5	J	3/4		D	5.8	6.5	4.8	---	11.0	7.6	1.8	3	2.1	9.8
188	64	23	D-1	18	A	3/4	(HDP); new, wet 3/4 in. (white) rope	D	5.8	6.5	4.8	---	11.0	7.6	1.8	3	2.1	11.3
189	68	35	D-1	19	J	3/4	(HDP)	D	5.8	6.5	4.8	---	11.0	7.6	1.8	3	2.1	10.5
190	66	29	D-1	20	A	3/4		D	5.8	6.5	4.8	---	11.0	7.6	1.8	3	2.1	13.7
191	60	14	D-2	13	A	3/4	(HDP); old, wet 5/8 in rope; flat cathead	G[a]	4	4.6	4.6	---	12	7.5	2.0	3.2	2.8	--
192	63	17	D-2	14	J	3/4		G	4	4.6	4.6	---	12	7.5	2.0	3.2	2.8	--
193	68	19	D-2	15	A	3/4	(HDP)	G	4	4.6	4.6	---	12	7.5	2.0	3.2	2.8	--
194	67	16	D-2	16	J	3/4	(HDP)	G	4	4.6	4.6	---	12	7.5	2.0	3.2	2.8	10.8
195	71	20	D-2	17	A	3/4	(HDP); rope thrown off cathead	G	4	4.6	4.6	---	12	7.5	2.0	3.2	2.8	8.3
196	61	37	D-2	18	J	1 3/4	Test through Kelly	G	4	4.6	4.6	---	12	7.5	2.0	3.2	2.8	16.7
197	60	36	D-2	19	A	1 3/4	(HDP)	G	4	4.6	4.6	---	12	7.5	2.0	3.2	2.8	15.8
198	65	10	D-2	20	J	1 3/4		G	4	4.6	4.6	---	12	7.5	2.0	3.2	2.8	13.5

[a] This operator normally uses 1 3/4 turns but for tests, he is using 3/4 turns.

Table 1 (Continued)

Series	ER_i (%)	N (B/ft)	Boring	Depth (m)	Sampler	Turns	Remarks	Operators	Cathead L (in)	Cathead OD (in)	Cathead ID (in)	Cathead RPM	Hammer H (in)	Hammer OD (in)	Hammer ID (in)	Knocking Head OD (in)	Knocking Head H (in)	Rate (B/min)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
199	42	58	F-1	11	J	1 3/4	(HDP); rigid hook on hammer; new white rope	D	4.3	7.9	6	---	10.4	7.8	1.6	3.0	2.4	13.9
200	63	25	F-1	12	A	1 3/4	Test through Kelly	D	4.3	7.9	6	---	10.4	7.8	1.6	3.0	2.4	17.8
201	61	25	F-1	13	J	1 3/4	(HDP)	D	4.3	7.9	6	---	10.4	7.8	1.6	3.0	2.4	19.0
202	50	25	F-1	14	A	1 3/4		D	4.3	7.9	6	---	10.4	7.8	1.6	3.0	2.4	23.5
203	53	19	F-1	15	J	1 3/4	Outside Kelly	D	4.3	7.9	6	---	10.4	7.8	1.6	3.0	2.4	12.8
204	86	0	G-1	26	J	1 3/4	Old, 3/4 in. rope; outside Kelly	H	5	4.6	4.6	---	10.5	8.0	1.8	3.5	2.8	17.5
205	33	69	G-2	6	J	2 3/4	(HDP); very deliberate; old, 5/8 in. rope; outside Kelly	I	4	6	5	Very Slow	13.0	7.6	2.0	3.5	2.8	7.6
206	77	52	G-1	27	J	1 3/4	Truncated cone; old, 5/8 in. rope; outside Kelly	H	5	4.6	4.6		16	5.9, 8	1.9	3.1	2.0	19.6
207	50	19	G-3	5	J	1 3/4	(HDP); Old, 5/8 in. rope; outside Kelly	J	5.1	6.0	4.5	---	13.6[b]	7.1	1.9	3.5	2.8	10.2
208	68	40	G-4	13.5	J	1 3/4	New, 3/4 in. rope; outside Kelly	K	5	6	4.5	---	13.6	7.1	1.8	3.0	2.5	17.8
209	86	--	G-4	14	K	TOMBI	New, 3/4 in. rope; outside Kelly	K	5	6	4.5	---	13.6	7.1	1.8	3.0	2.5	11.2
210	92	21	H-1	35	J	1 3/4	Old, 1/2 in. rope; outside Kelly; usually inside	L	3.1	4.3	4.3	---	9.8	8.1	1.8	3.0	2.8	18.9
211	80	5	I-1	5	J	1 3/4	New, 1/2 in. nylon rope; outside Kelly	M	6	6.5	4.8	---	10.6	8.0	1.8	3.5	2.8	--
212	71	20	I-1	6	J	1 3/4	(HDP); old, 1/2 in. Manila rope	M	6	6.5	4.8	---	10.6	8.0	1.8	3.5	2.8	--

[b] Cathead rope attached to one side of hammer.

Table 1 (Continued)

Series	ER_i (%)	N (B/ft)	Boring	Depth (m)	Sampler	Turns	Remarka	Operators	Cathead L (in)	Cathead OD (in)	Cathead ID (in)	Cathead RPM	Hammer H (in)	Hammer OD (in)	Hammer ID (in)	Knocking Head OD (in)	Knocking Head H (in)	Rate (B/min)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
213	75	23	I-1	7	J	1 3/4	New, 1/2 in. rope; (HDP)	M	6	6.5	4.8	---	10.6	8.0	1.8	3.5	2.8	--
214	69	20	I-1	8	J	TOMBI	New, 1/2 in. rope; Wakamatsu method[c] of releaae	M	6	6.5	4.8	---	10.6	8.0	1.8	3.5	2.8	--
215	82	42/10cm	J-1	29	J	1 3/4	Old, 5/8 in. rope	N	6	4.5	4.5	200 Est.	10.5	8.0	1.8	3.0	2.5	--
216	74	50/26cm	J-1	30	J	1 3/4	Old, 5/8 in. rope	N	6	4.5	4.5	200 Est.	10.5	8.0	1.8	3.0	2.5	--
217	80	21	J-1	31	J	TOMBI		N	6	4.5	4.5	200 Est.	10.5	8.0	1.8	3.0	2.5	--
218	57	17	K-1	15	J	1 3/4	Old, 5/8 in. rope, inside Kelly; (HDP)	O	6	6.5	5	129	13	7.8	2.1	3.5	2.8	25
219	83	50/15cm	K-1	16	J	TOMBI	Uaing eyelet on hammer, not chain	O	6	6.5	5	180	13	7.8	2.1	3.5	2.8	--
220	62	50/11cm	K-1	17	J	1 3/4		O	6	6.5	5	---	13	7.8	2.1	3.5	2.8	--
221	68	50	L-1	14	J	1 3/4	Old, wet, 5/8 in. rope, through Kelly	P	6.6	6.5	4.5	---	10.2	8.0	1.8	3.4	2.6	--

[c] A drill rod clamp was diaengaged using a hammer, permitting inatantaneous release.

Table 2. Summary of Direct Measurement Data Comparing N_{US} and N_J

Boring No. (1)	Depth (m) (2)	Blow Counts in Blows/Foot		Fig Ref. (5)
		N_{US} (meas.) (3)	N_J (meas.) (4)	
A 1,2	11	38.2	57.2	17a
A 1,2*	12	28.2	14.6	17a
A 1,2	13	4.5	5.5	17a
C 1,2	11	16.1	25.5	17c
C 1,2	12	33.5	38.0	17c
C 1,2	15	34.5	38.0	17c
C 1,2	16	27.0	44.5	17c
C 1,2*	17	30.0	18.0	17c
C 1,2	18	22.6	32.5	17c
C 1,2	19	18.3	22.6	17c
C 1,2	20	25.5	26.5	17c
D 1,2	14	8.5	15.8	18a,b
D 1,2	15	19.0	16.5	18a,b
D 1,2	16	14.8	15.8	18a,b
D 1,2	17	20.9	23.7	18a,b
D 1,2	18	21.6	33.2	18a,b
D 1,2	19	31.8	35.0	18a,b
D 1,2*	20	28.1	9.6	18a,b

Notes: 1) Direct measurement blow counts were normalized to average energy ratio of 68 percent.
2) Asterisk indicates data was not used because of abrupt changes in N Values

Table 3. Summary of Regression Analyses

Condition	Equation
Data in figure 25	$N_{US} = 0.78\ N_J$ $N_{US} = 2.67 + 0.70\ N_J$ $N_{US} = 1.36\ N_J^{0.84}$
Data in figure 26	$N_{US} = 0.79\ N_J$ $N_{US} = 3.27 + 0.67\ N_J$ $N_{US} = 1.83\ N_J^{0.75}$

Note: The residual standard deviations for the above equations are approximately four.

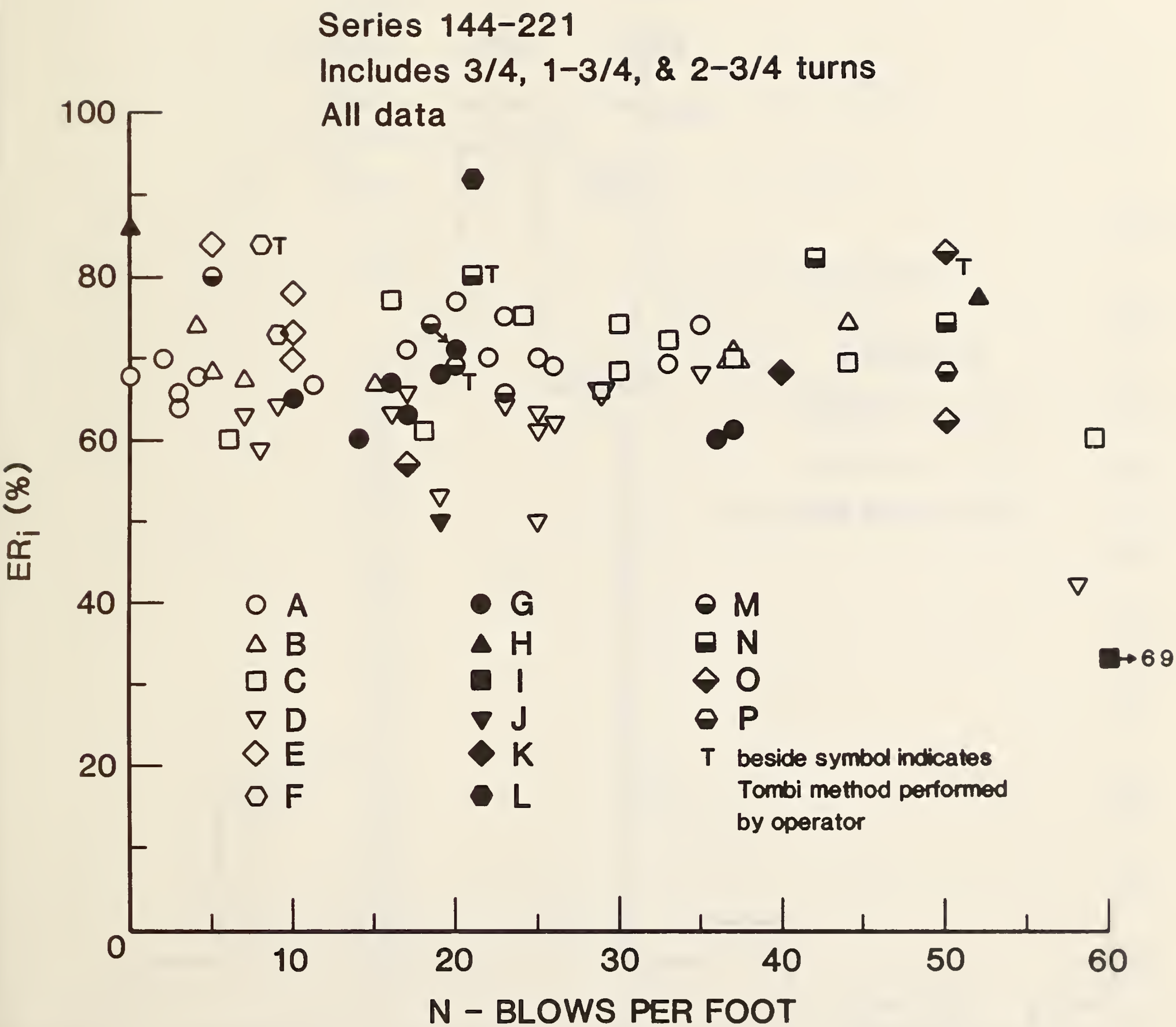

Figure 11. Summary of ER_i data vs N-value by operator

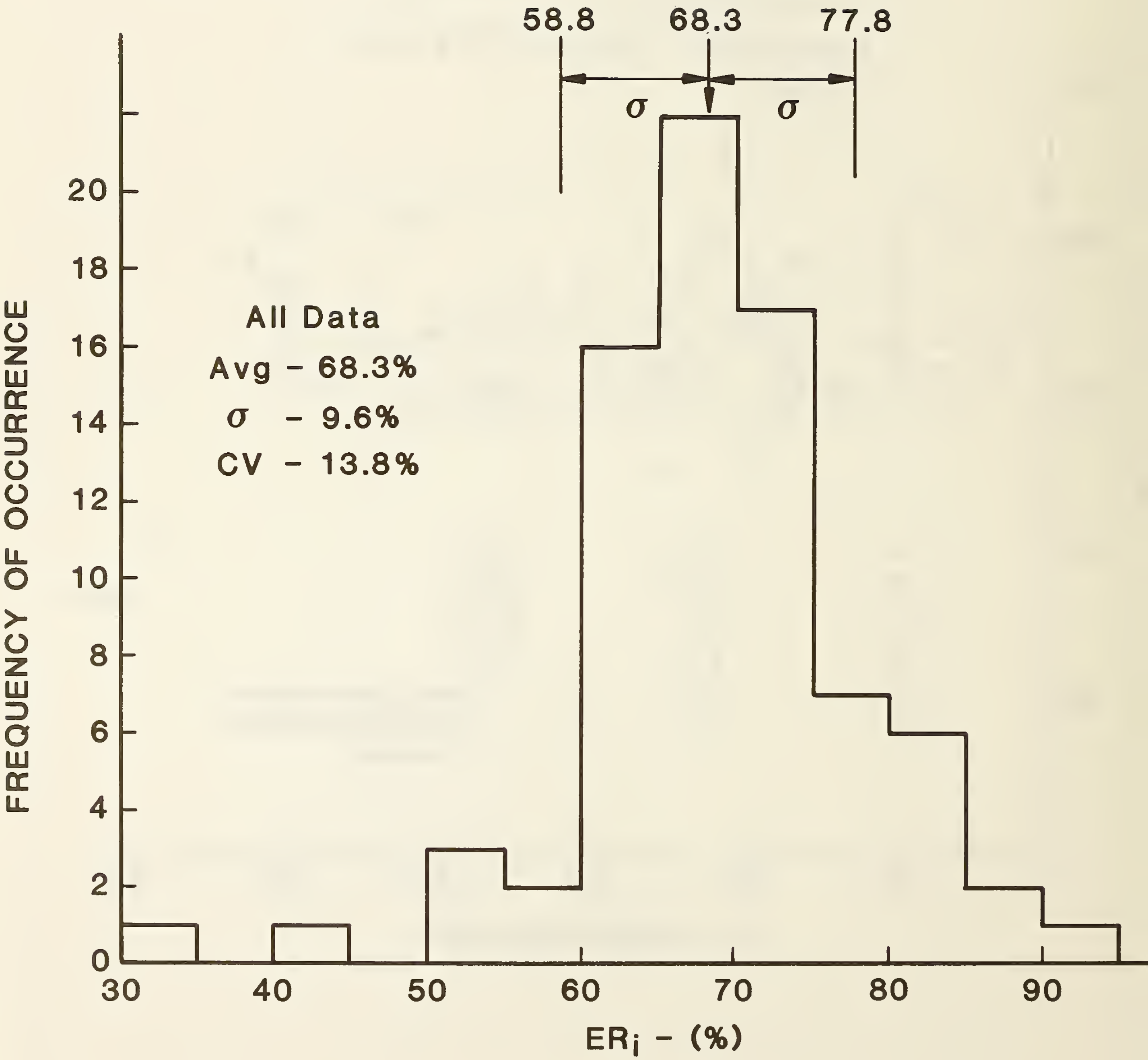

Figure 12. Frequency diagram of ER_i results

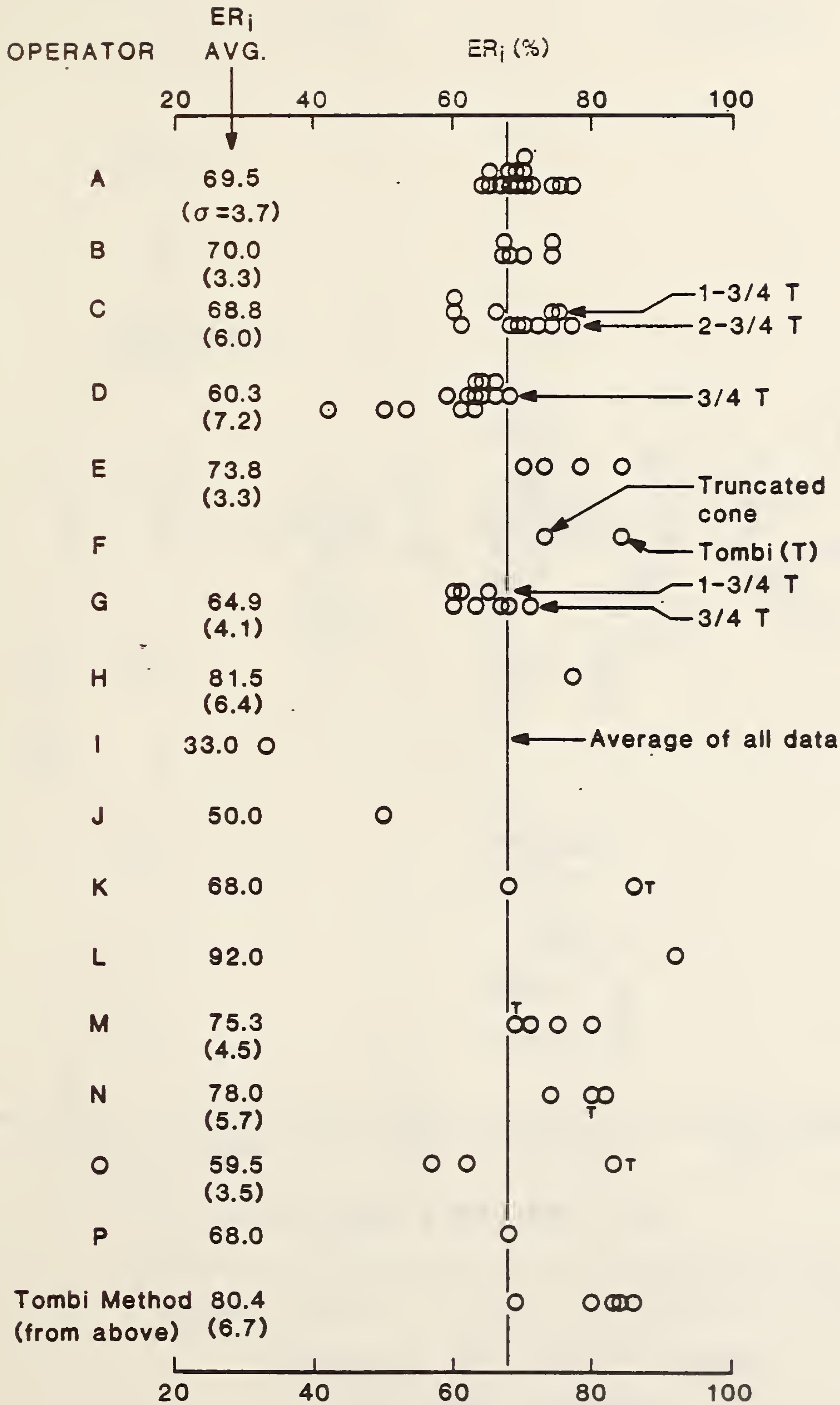

Figure 13. Energy ratio variation by operator

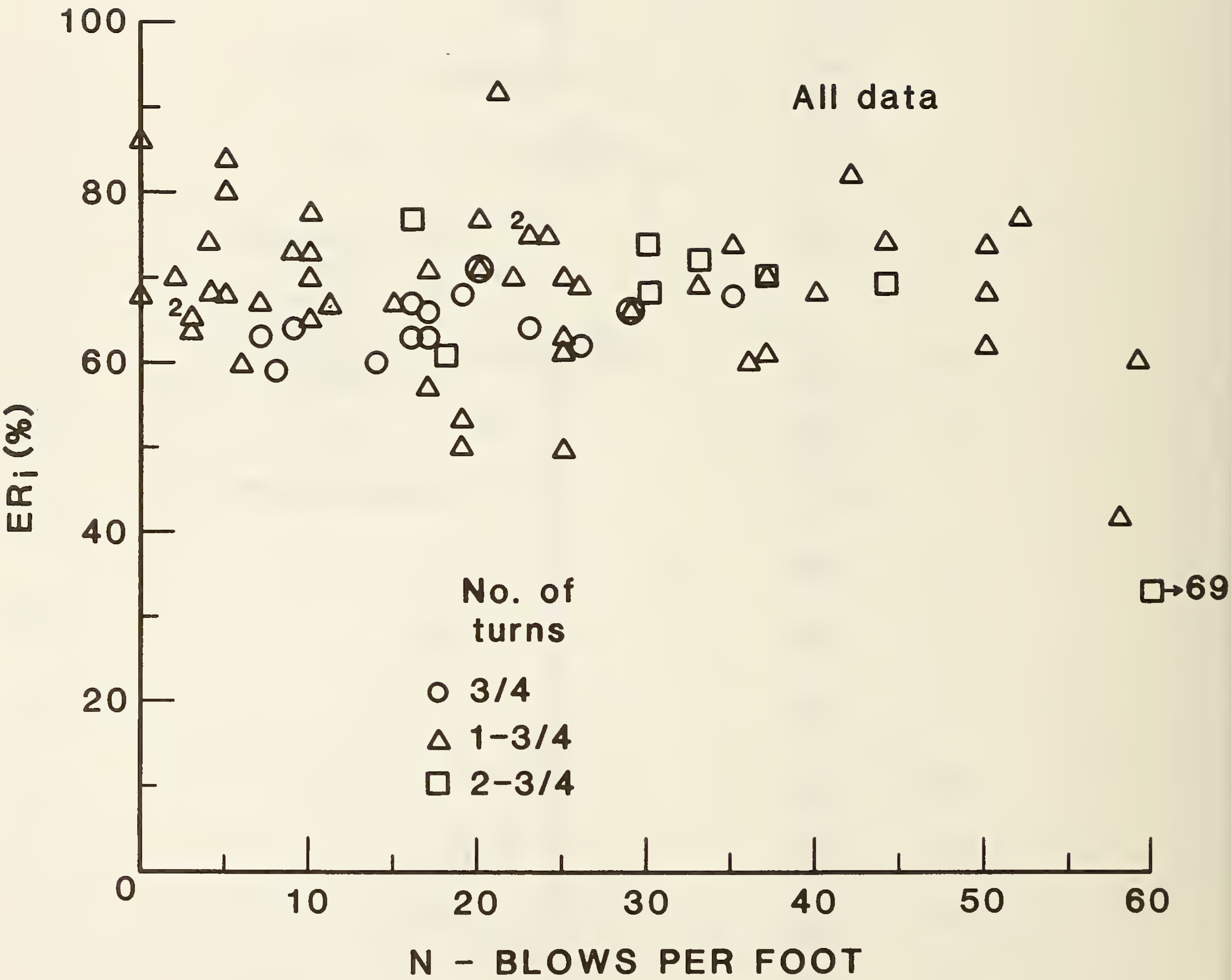

Figure 14. ER_i vs N-value showing effects of number of turns of rope around the cathead

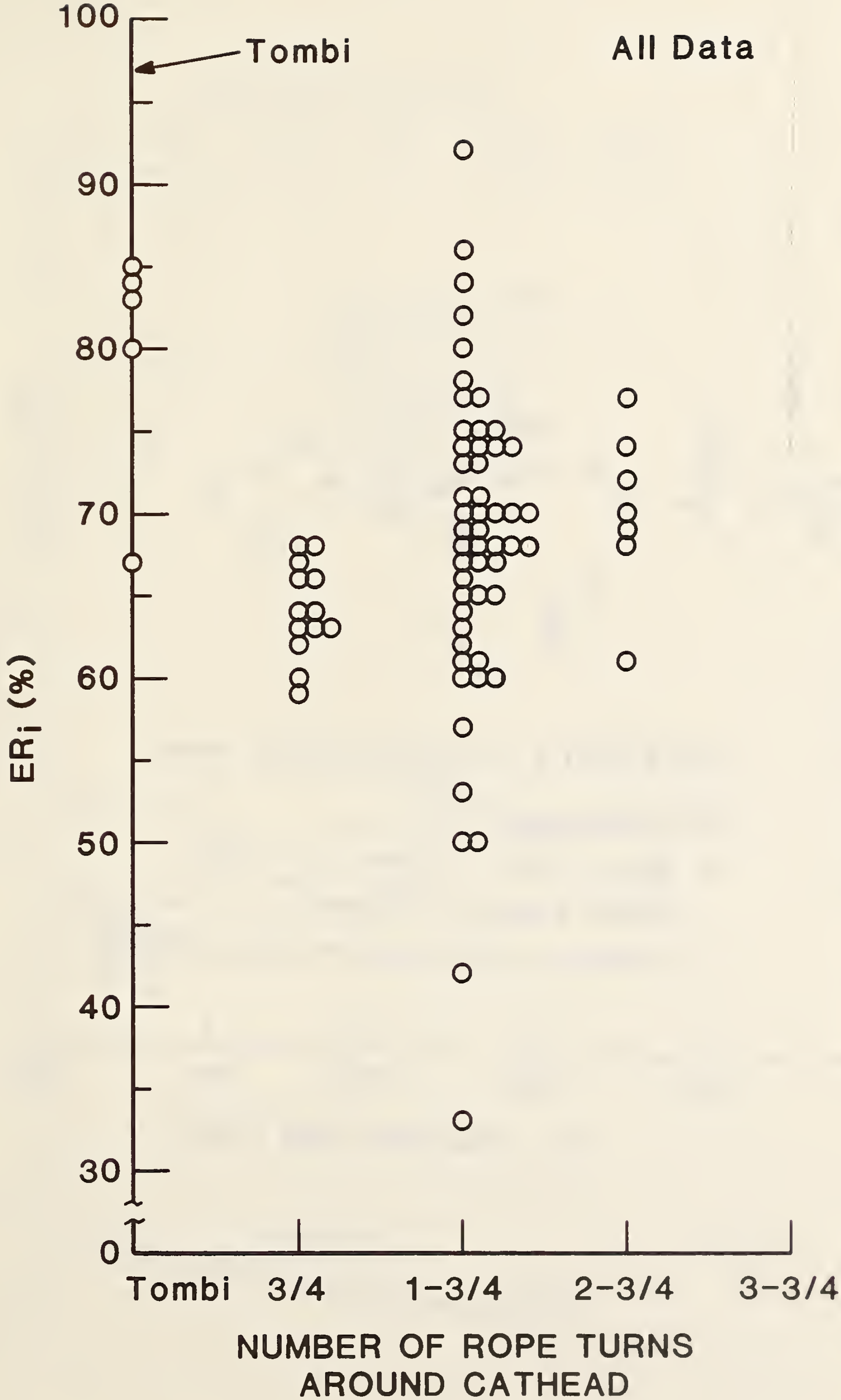

Figure 15. ER_i vs number of rope turns around the cathead

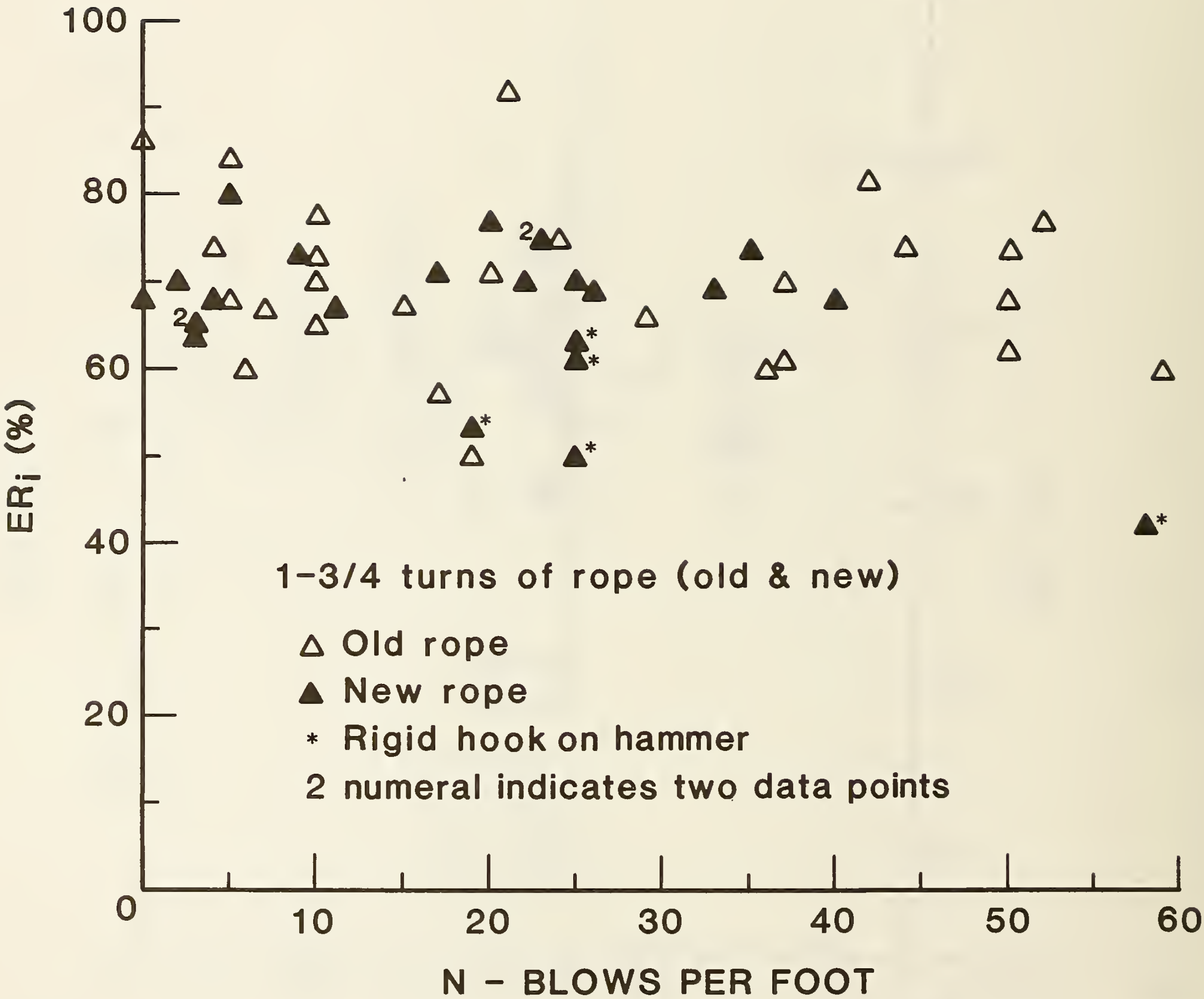

Figure 16. ER_i vs N showing the effect of rope age using 1-3/4 turns of rope around the cathead

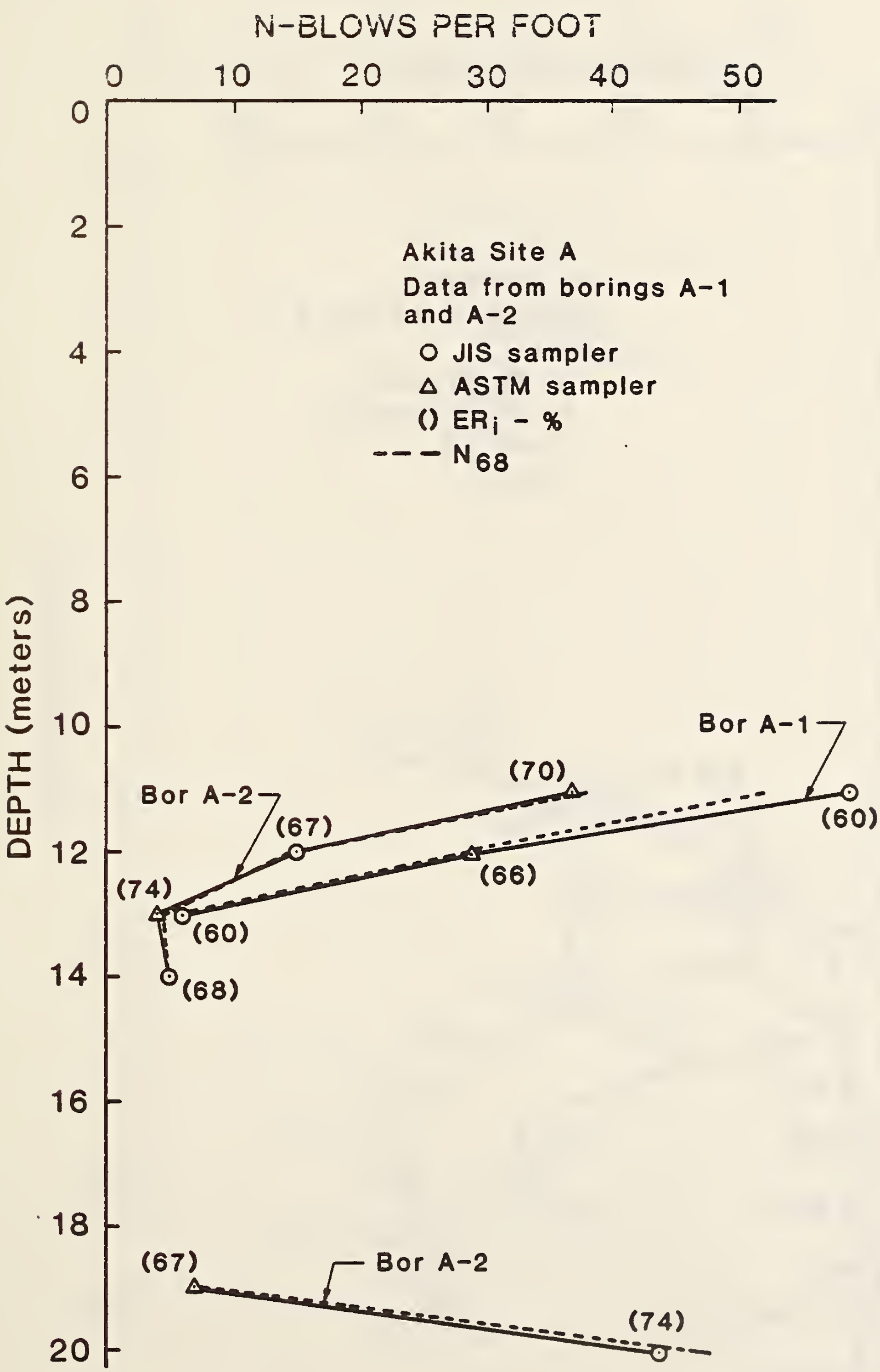

Figure 17a. N-value vs depth profile for the Akita area: borings A-1 and A-2

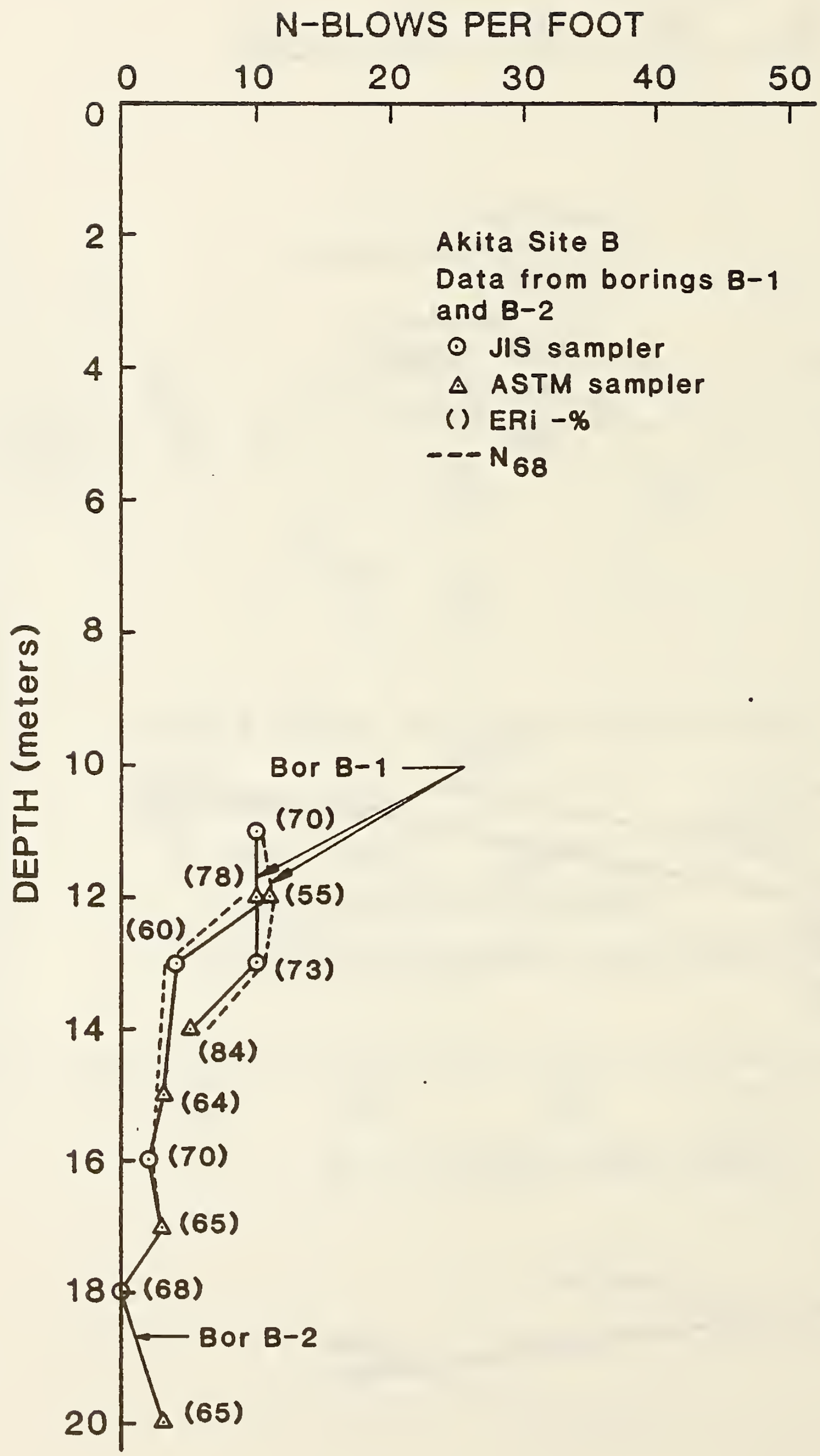

Figure 17b. N-value vs depth profile for Akita area: borings B-1 and B-2

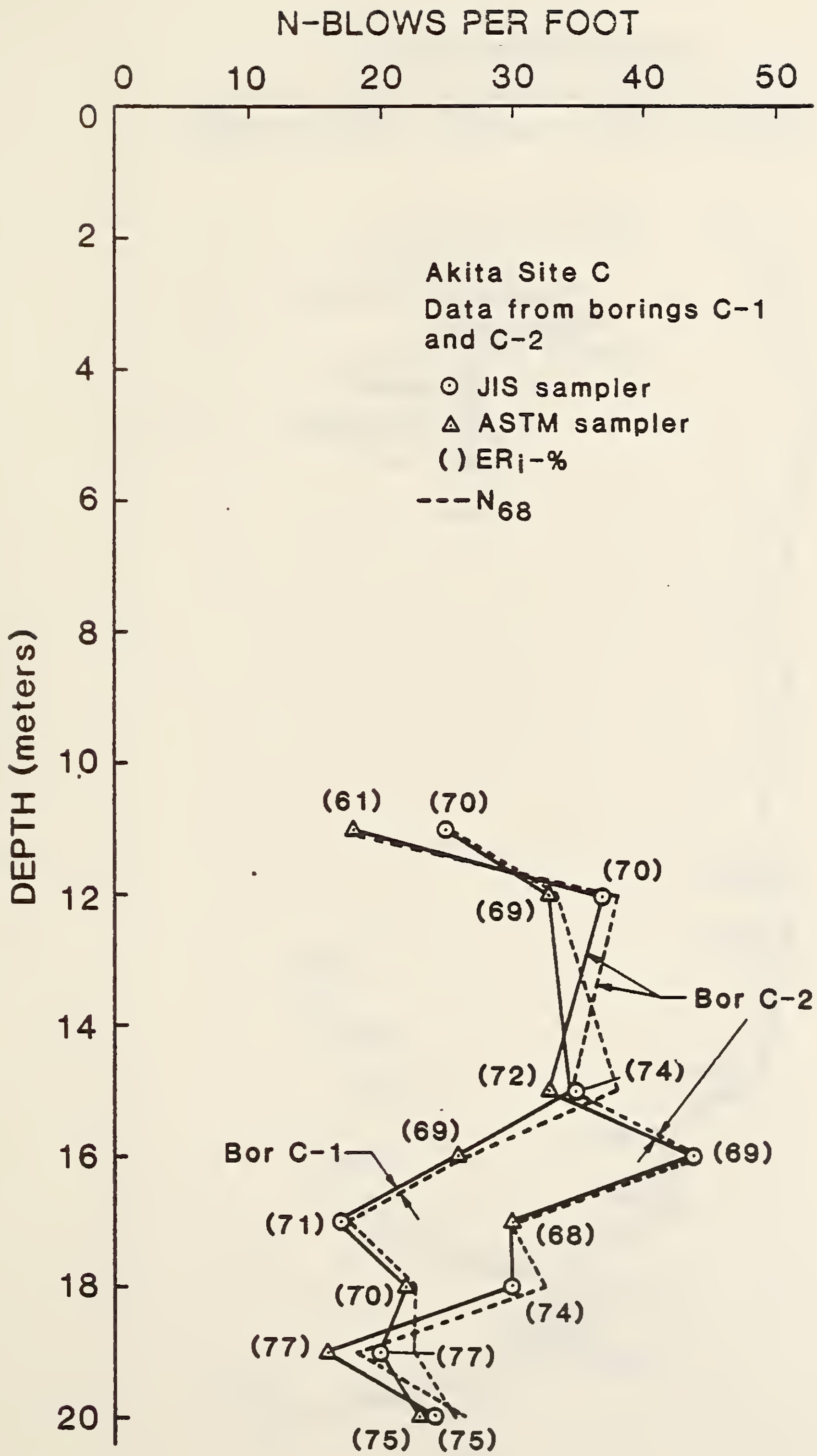

Figure 17c. N-value vs depth profile for Akita area: borings C-1 and C-2

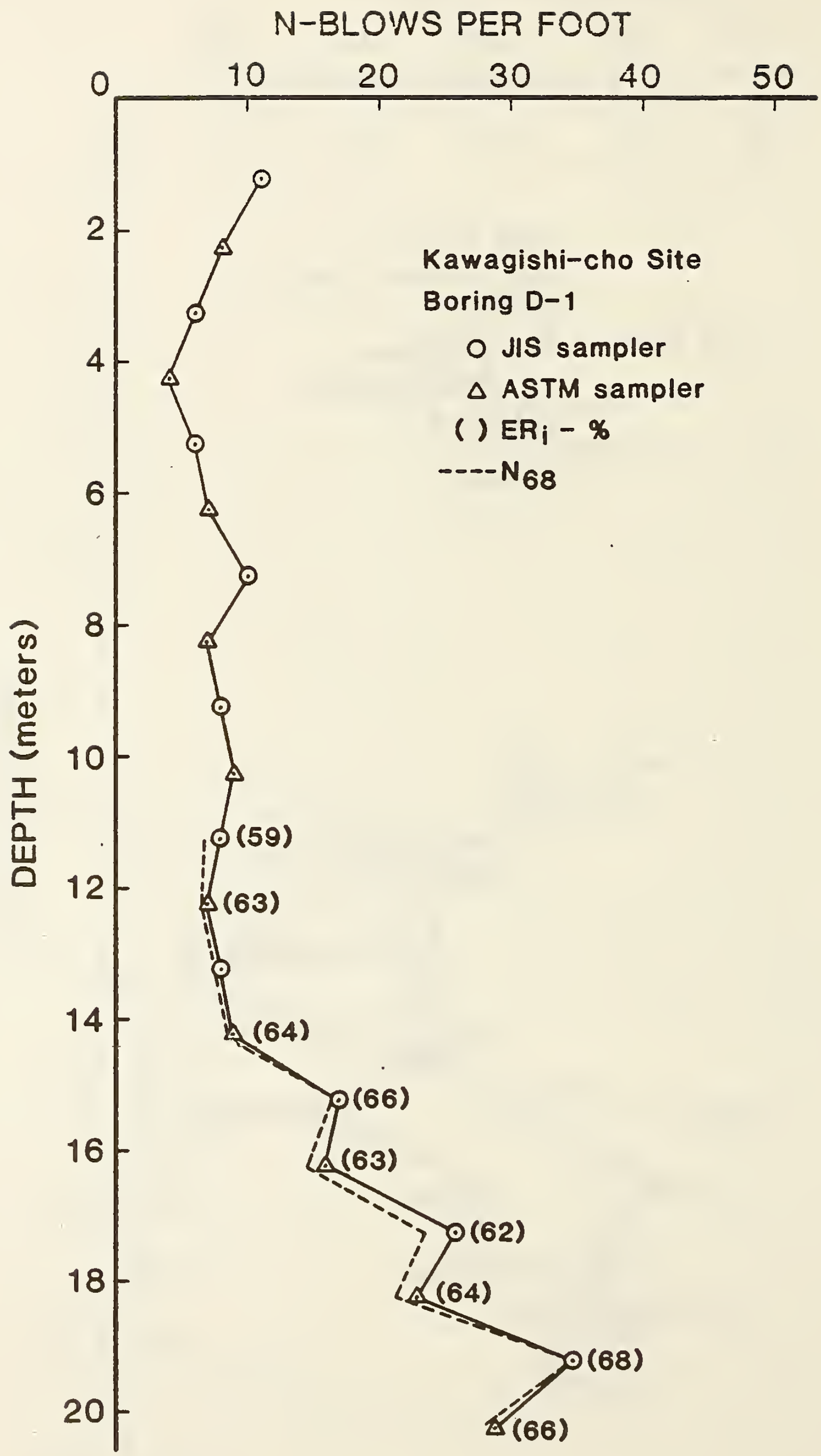

Figure 18a. N-value vs depth profiles for the Niigata areas: boring D-1

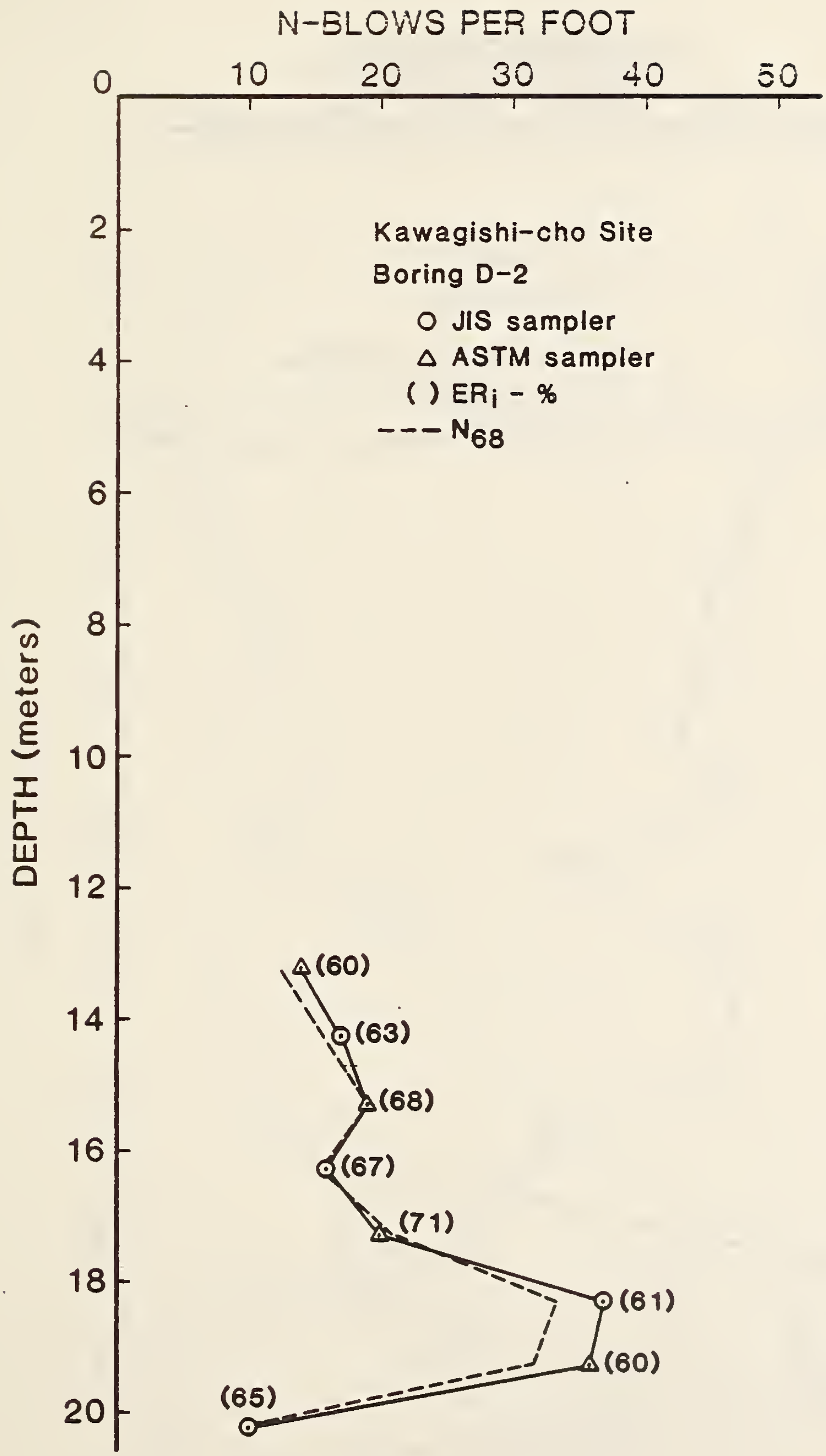

Figure 18b. N-value vs depth profiles for the Niigata areas: boring D-2, Kawagishi-cho site

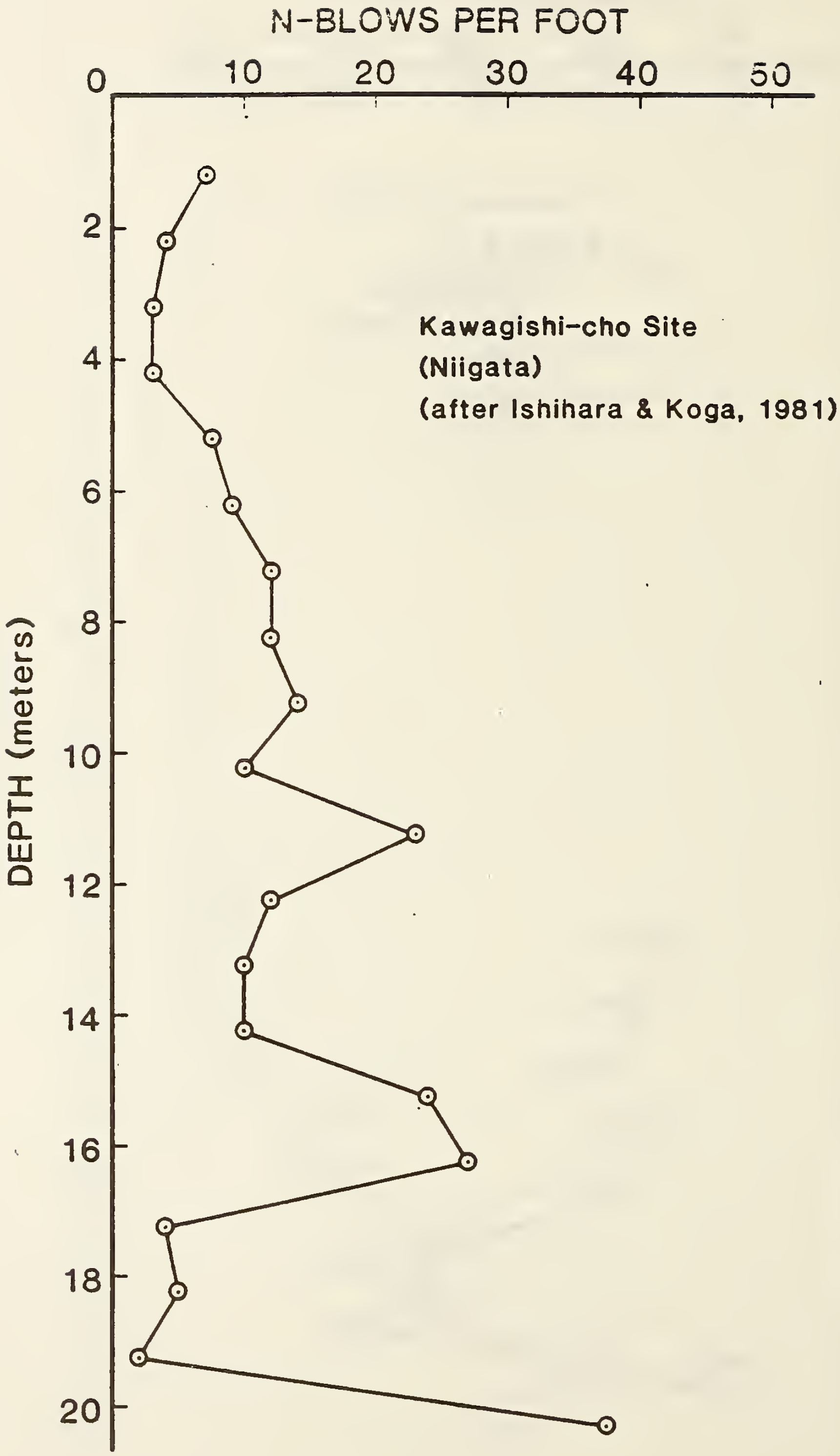

Figure 19. N-value vs depth profile for the Kawagishi-cho site in Niigata (after Ishihara and Koga, 1981)

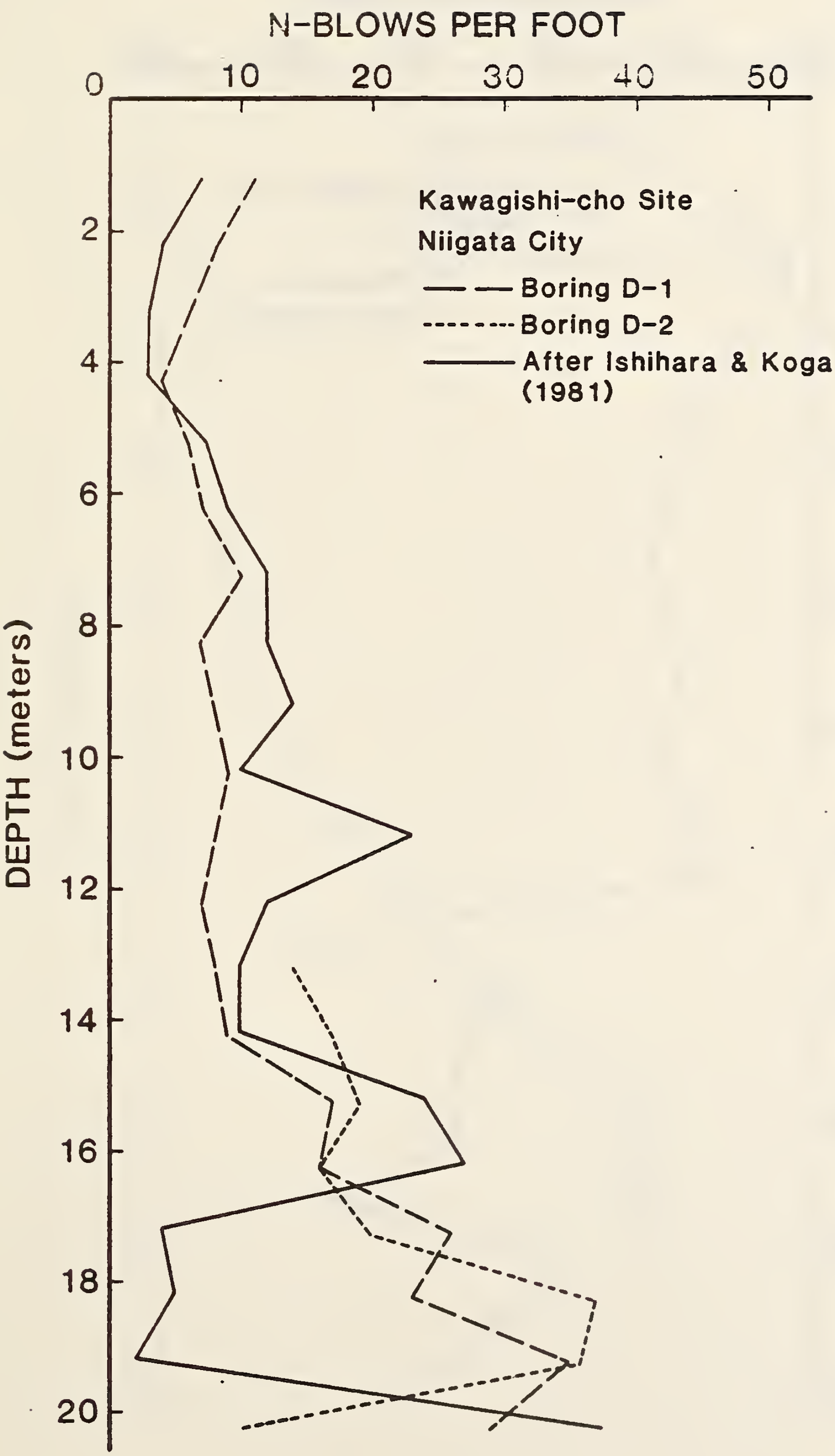

Figure 20. N-value (uncorrected for Energy Ratio) vs depth compiled from figures 18a, 18b, and 19

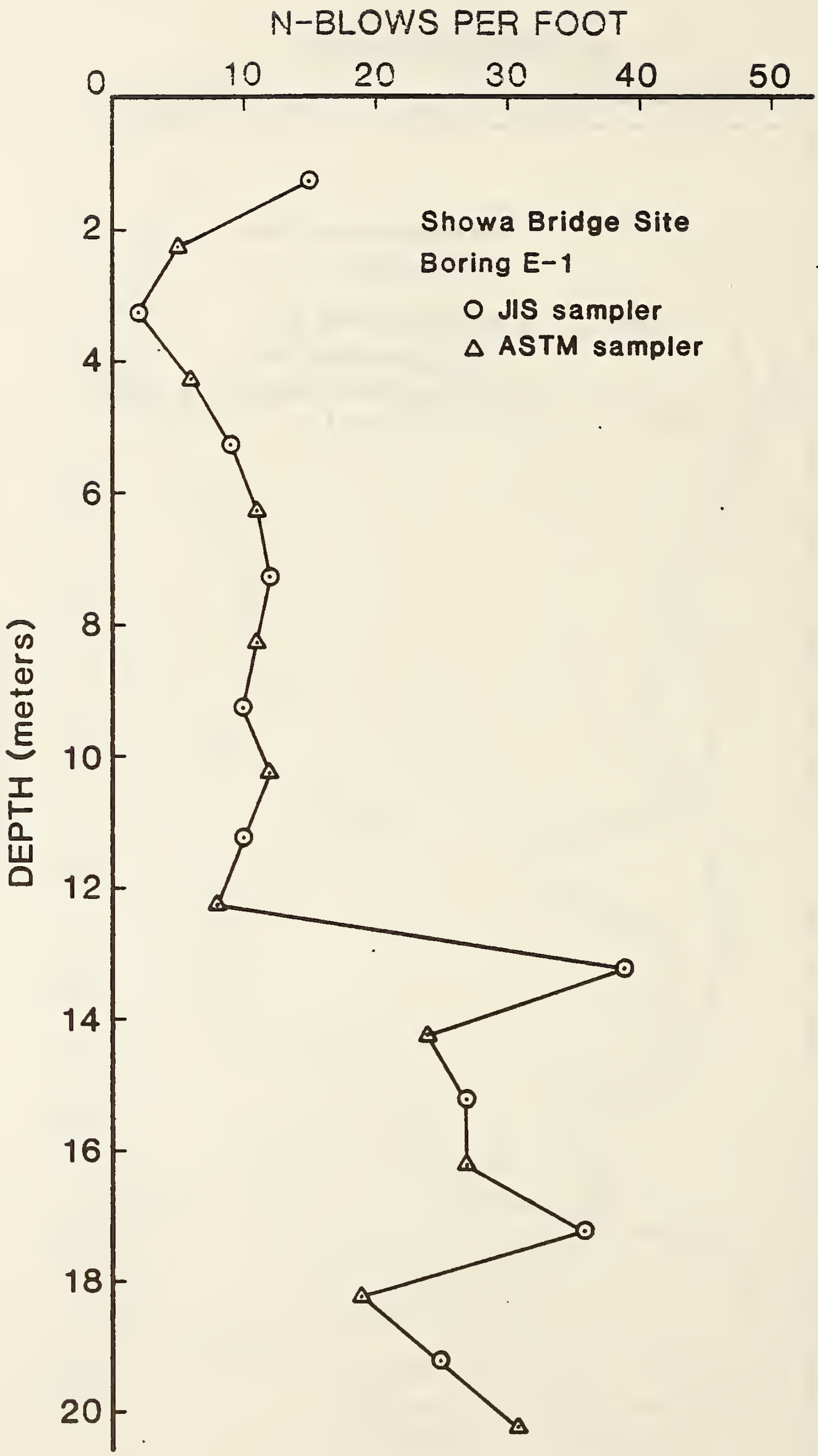

Figure 21. N-value vs depth for boring E-1, the left bank of the Showa bridge site, liquefied site

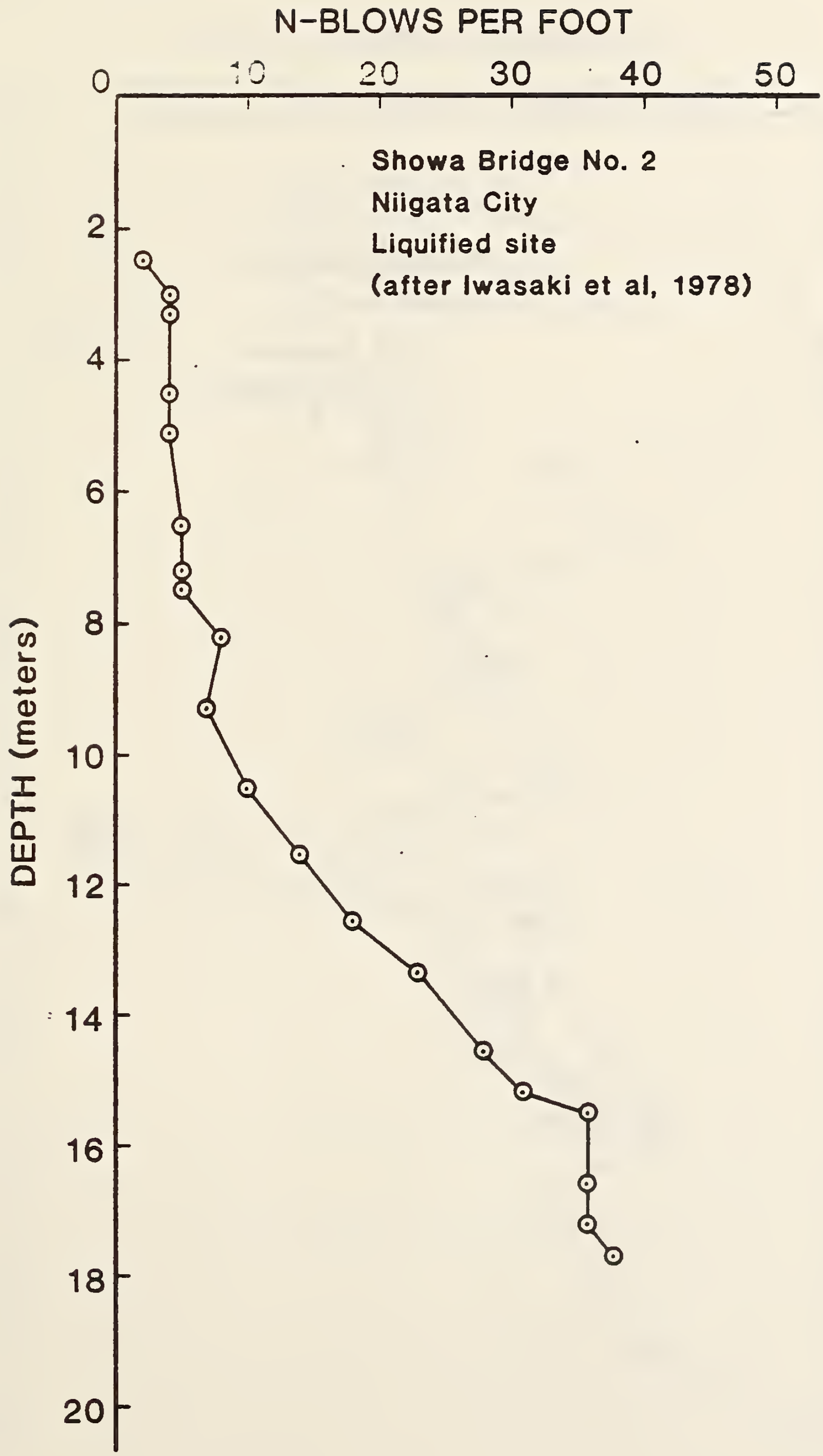

Figure 22. N-value vs depth for Showa bridge no. 2, liquefied site (after Iwasaki et al., 1978)

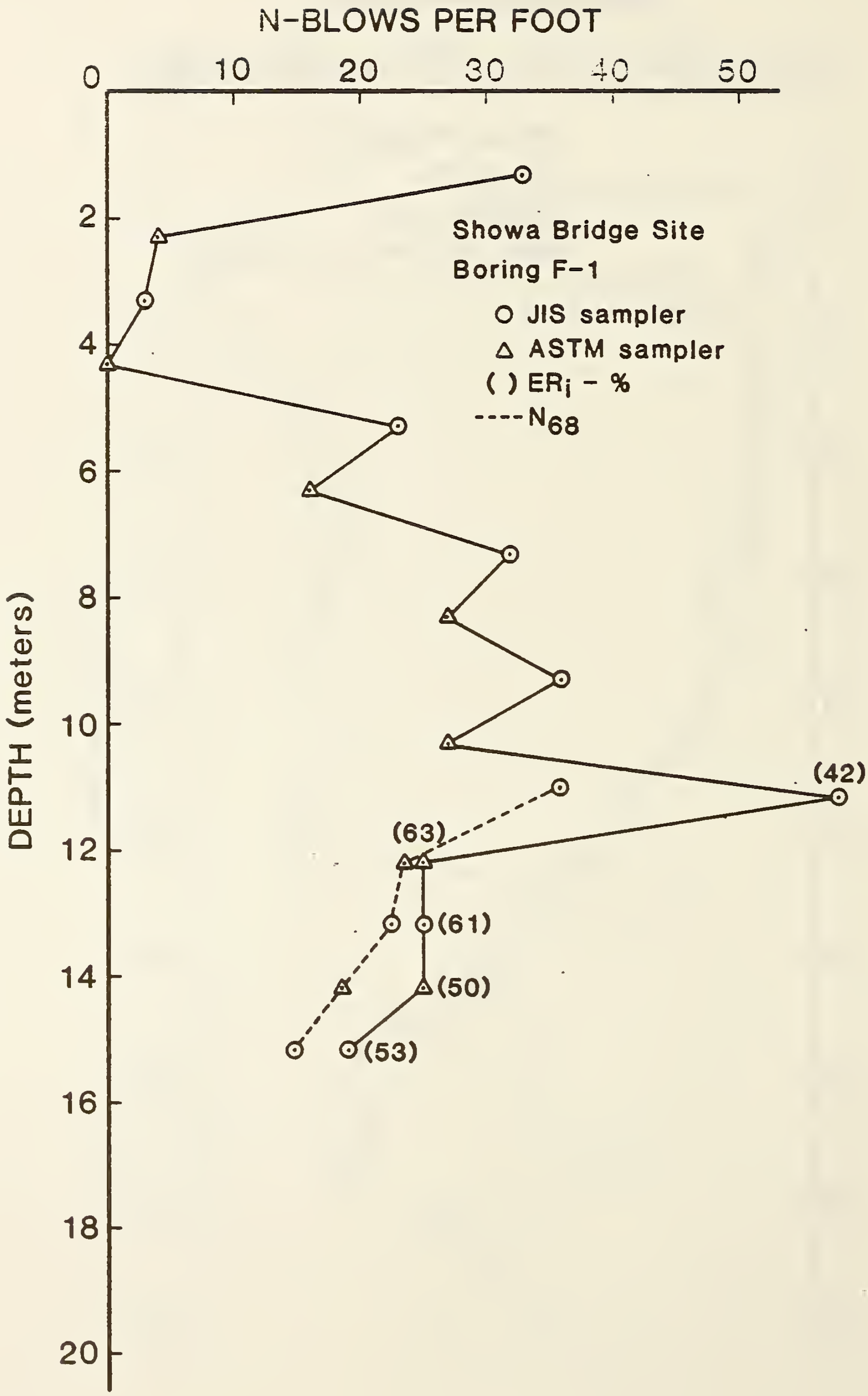

Figure 23. N-value vs depth for boring F-1, the Right Bank of the Showa bridge, a non-liquefied site

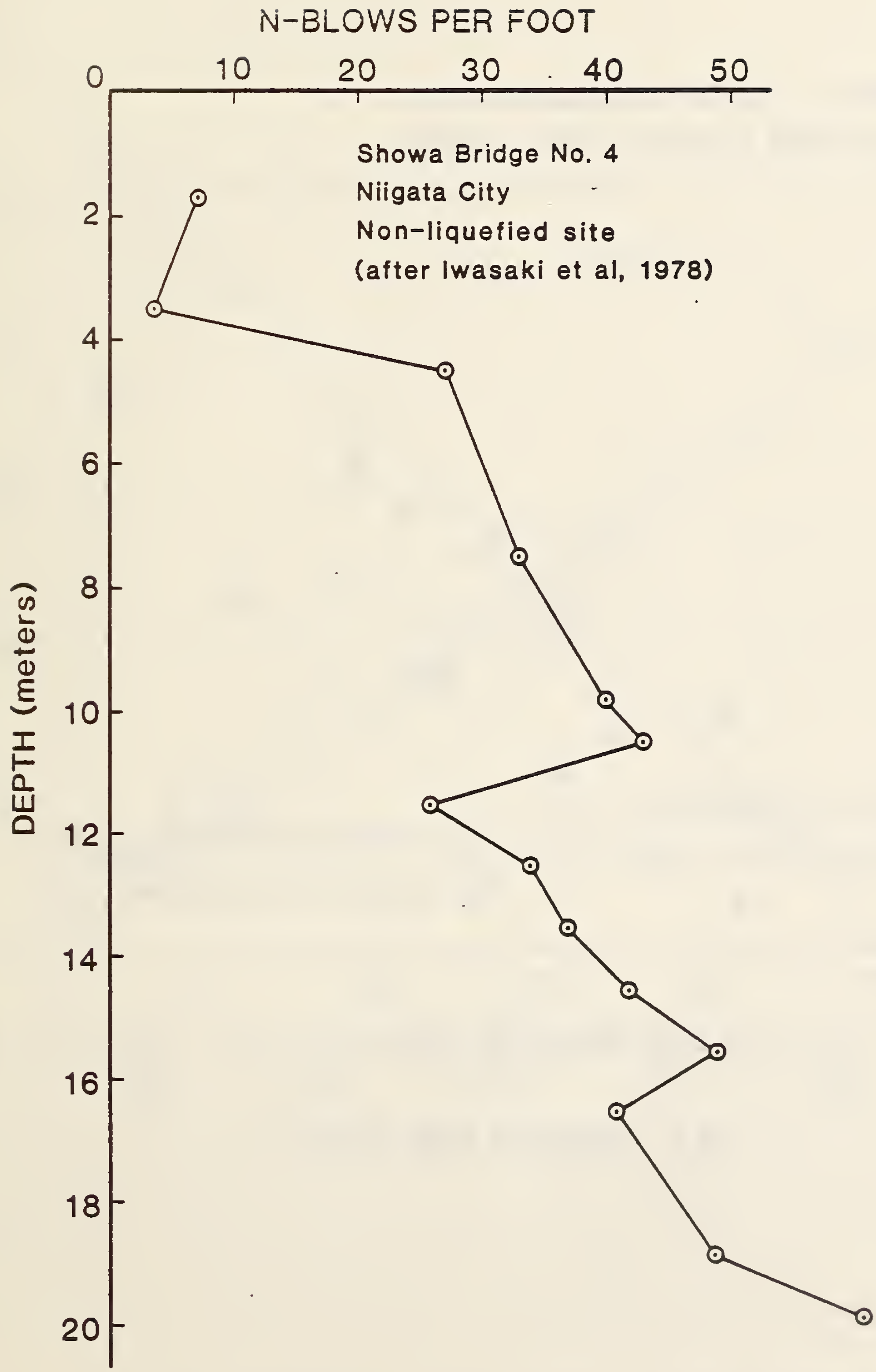

Figure 24. N-value vs depth for Showa bridge no. 4, a non-liquefied site (after Iwasaki et al., 1978)

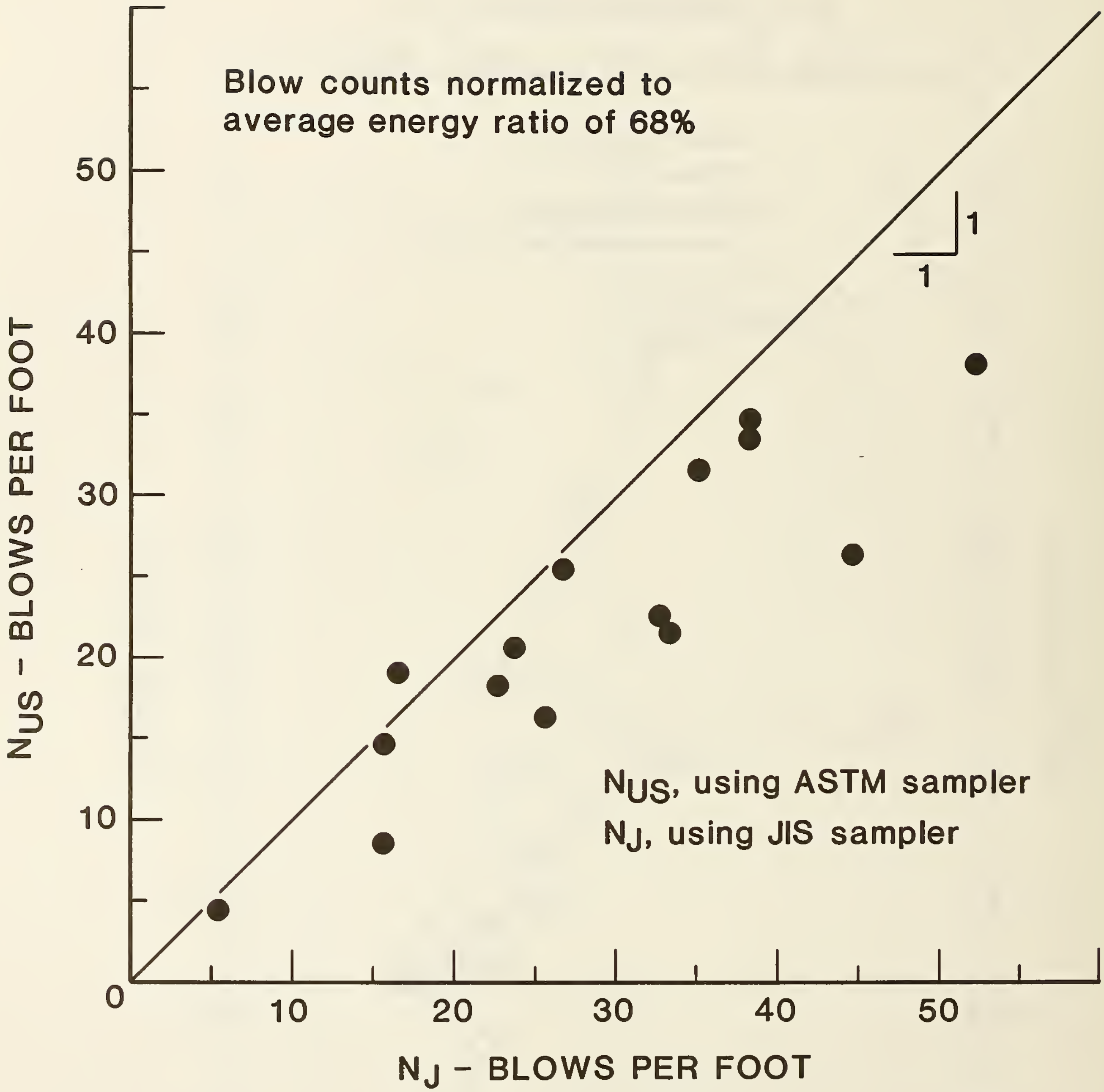

Figure 25. N-value correlation between JIS and ASTM samplers, normalized to average Energy Ratio of 68 percent, direct measurement data

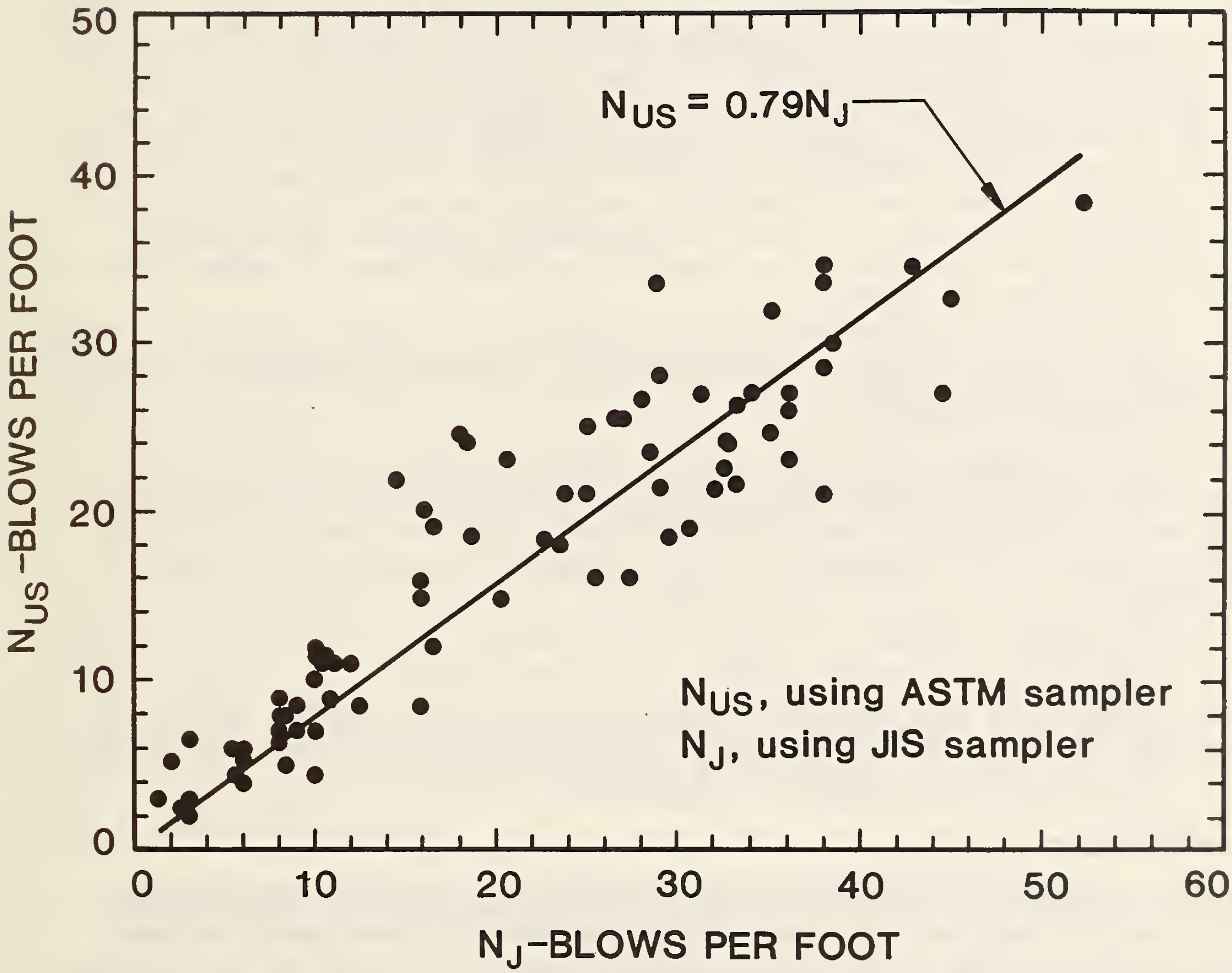

Figure 26. N-value correlation between JIS and ASTM samplers, direct measurement data and data obtained from interpolation

6. APPLICATION

6.1 COMPARISON OF JAPANESE ER_i and UNITED STATES ER_i

It appears that the average value of energy ratio in Japan is approximately 68 percent of the available free-fall energy. This observation is based on field tests at three locations and comparison of blow counts obtained up to 20 years ago in the Niigata area where the soil profiles appear to be similar. This value compares with approximately 55 percent energy ratio for U.S. data published by Kovacs et al., (1983). It must be recognized that the U.S. data for safety hammers varies between approximately 40 and 75 percent while the data for donut type hammers varies from 30 to about 55 percent with two data points at approximately 70 percent. Thus, the scatter of U.S. data is extremely broad compared to the more narrow spread of data from Japan, as summarized in table 1 and shown in figure 12.

6.2 EVALUATION OF THE RATIO OF N_{US}/N_J TAKING INTO ACCOUNT ENERGY RATIO AND THE SAMPLER SHAPE FACTOR

According to Schmertmann, (1975) and Schmertmann and Palacios (1979), the N-value is inversely proportional to the energy used to drive the sampler. Thus we could approximate the blow count under condition 2 knowing the blow count and energy for condition 1 and the energy for condition 2 by means of eq. (6.1).

$$N_1E_1 = N_2E_2 \tag{6.1}$$

Such relationships have also been shown by Kovacs et al. (1983). We can now expand eq. (6.1) by including a sampler shape factor and performing an experiment as we have done in Japan. For example,

$$(N \cdot E \cdot S)_{US} = (N \cdot E \cdot S)_J \tag{6.2}$$

where the subscript, US, indicates the blow count and energy ratio obtained using the ASTM sampler, the subscript, J, indicates the blow count and the energy ratio obtained using the JIS sampler, and S is the sampler shape factor required to balance the equation. In this particular case, the energy ratio on both sides of the equation can be equal to 68 percent, the average energy obtained in Japan. Using eq. 5.1, we can obtain a relationship between the blow counts at the same energy between the ASTM sampler and the JIS sampler.

It is now possible to compute the ratio of N_{US} to N_J for the cathead and rope method used in both countries based on an average energy ratio and effects of sampler geometry. Substituting the values of average energy ratio into equation 6.2 and assuming S_J equals unity, we find that the ratio of N_{US} to N_{cj} equals 0.98 or approximately unity.

$$\frac{N_{US}}{N_{cj}} = \frac{ER_J\ S_j}{ER_{US}\ S_{US}} = \frac{67.4 \times 1.0}{55 \times 1.25} = 0.98 \tag{6.3}$$

It should be remembered that the range of U.S. energy ratio is quite large and as a result, the results of equation 6.3 will vary from approximately 1.80 when a 30 percent energy ratio is used to a low value of 0.72 when 75 percent energy ratio is used.

Applying the same principles, and solving for the relationship between N_{US} and N_{tj} for the data obtained using the Tombi method we find the values after inserting them into equation 6.2 as shown in equation 6.4. The corresponding value is 1.17 and not the value of 1.4 as suggested by Tokumatsu and Yoshimi (1983). Note Tokumatsu and Yoshimi (1983) have not introduced the factor of the differences in internal shape between the ASTM and JIS sampler.

$$\frac{N_{US}}{N_{cj}} = \frac{ER_J\ S_j}{ER_{US}\ S_{US}} = \frac{80.4 \times 1.0}{55 \times 1.25} = 1.17 \qquad (6.4)$$

Again, the value obtained in eq. (6.4) will vary depending upon the actual value of U.S. energy ratio used. For example, the ratio is 2.15 if the U.S. energy ratio is 30 percent, while a ratio of 0.86 is obtained when a value of 75 percent for the U.S. energy ratio is used. Therefore, we can conclude that the ratio of N_{US}/N_J will vary as shown in table 4, assuming that the blow count rate difference between the U.S. and Japan (US @ 30 to 60 blows per minute and Japan @ 7 to 25 blows per minute) does not influence the ratio.

The aspect of blow count rate difference must be addressed before final ratios can be estimated. The use of bottom discharge drill bits used by the Japanese is another factor which is not considered in the U.S./Japanese blow count ratio. Schmertmann (private communication, 1984) relates a case "where the use of bottom discharge bits in a sand reduced blow counts by an average factor of 2.06." Parsons (1966) gives field blow count evidence where the average N-value in auger borings made with drilling mud (drilling mud was used in this study) was about 2.5 times those in cased borings with water used as the drilling fluid.

6.3 EVALUATION OF JAPANESE DATA BASE AND EFFECT ON PRESENT ENGINEERING DESIGN CURVES FOR LIQUEFACTION POTENTIAL

Based upon the discussion and data presented in sections 5 and 6 of this report, it appears that the blow count ratio between U.S. and Japan engineering practice is, <u>on the average</u>, approximately equal to unity when considering only energy and sampler effects, and not considering rate and bottom discharge. At this time, finer resolution of the data is not possible because of the wide variability in the conditions used for the Standard Penetration Test and the wide variability in the energy measurement data.

Table 4. Summary of Blow Count Ratios, N_{US}/N_J for Different Assumed Energy Ratio Conditions

Release Mechanism	U.S. ER_i (%)	JAPAN ER_i (%)	$\frac{N_{US}}{N_{cj}}$	$\frac{N_{US}}{N_{tj}}$
Cathead and Rope	30	67.4	1.80	
Cathead and Rope	75	67.4	0.72	
Cathead and Rope	55	67.4	0.98	
Tombi Method	30	80.4		2.15
Tombi Method	75	80.4		0.86
Tombi Method	55	80.4		1.17

7. FINDINGS

Based on this investigation, it was found that:

1. The (1983) equipment and procedures used to perform the Standard Penetration Test in Japan differ from the 1983 engineering practice in the United States. These variations result in differences in the average energy passing through the drill rods, ER_i. When the cathead and rope method is used in Japan as the hammer release mechanism, ER_i averages approximately 67 percent. When the Tombi method (free-fall) is used, ER_i averages approximately 80 percent. These values compare with an average of approximately 55 percent for published U.S. data from cathead and rope Standard Penetration Tests.

2. It was observed that the bore hole drilling mud level was not maintained when the drill rods were withdrawn. This practice and the use of bottom discharge bits could result in lower blow counts when compared to blow counts obtained using U.S. engineering practice.

3. There is less scatter in the Japanese energy data than the U.S. energy data.

4. The energy ratios for the Tombi method is approximately 1.19 times the average energy delivered in the Japanese cathead and rope method. This ratio compares favorably with the ratio of 1.2 given by Tokimatsu and Yoshimi (1983).

5. The number of turns of rope around the cathead and rope age had relatively little effect on ER_i in Japan in contrast to U.S. experience.

6. The effect of sampler type on the standard penetration resistance, N, is significant. On the average, standard penetration resistance values obtained using an ASTM sampler were found to be approximately 20 percent lower than penetration resistance values obtained using the Japanese JIS sampler at the same energy ratio.

7. The ratio of N_{US}/N_J varies as shown in table 4, section 6.2. However, on the average, the ratio computes to be 0.98 when the cathead and rope method is used as the hammer release mechanism. When the Tombi method is used to obtain the Japanese N-value, the ratio is 1.17. These average ratios consider energy and sampler, but not rate and bottom discharge effects, nor other important effects possibly not identified in this study.

8. CONCLUSIONS

The design curves to evaluate liquefaction potential should be used with caution because of the variability in the ratio of U.S. blow counts to Japanese blow counts, N_{US}/N_J. For the cathead and rope method as the hammer release mechanism, and considering only energy and sampler effects, the ratio of N_{US}/N_J varied from 0.72 to 1.80. When the Tombi method was used, the ratio of N_{US}/N_J varied from 0.86 to 2.15. Because of this variability, it would be prudent to reexamine the design curves used to evaluate liquefaction potential considering this variation. It may also be necessary to reference the design curves to a specific energy. A suggested approach to energy normalization has been given by Kovacs et al (1984).

9. ACKNOWLEDGMENTS

This cooperative study was supported in part by project-related engineering and scientific study funds of the Bureau of Reclamation, U.S. Department of the Interior, the Naval Facilities Engineering Command and the Waterways Experiment Station. The field data acquisition was managed by the National Bureau of Standards while the National Bureau of Standards and the Bureau of Reclamation also provided engineering manpower. E. D. Anderson of NBS and J. A. Farrar of the Bureau of Reclamation provided assistance to William Kovacs during the field program. The OYO Corporation of Tokyo and the Public Works Research Institute of the Ministry of Construction of the Japanese acted as hosts. The OYO Corporation provided logistical support for data acquisition that included transportation of field equipment and personnel, drilling of bore holes, and performing the necessary field tests.

The regression analysis for table 2 was performed by S. Leigh and F. Y. Yokel. The figures were prepared by R. Mele and K. Mackley.

The manuscript was critically reviewed by N. J. Carino, J. H. Schmertmann, and F. Y. Yokel. The assistance of the abovementioned organizations and individuals is greatly appreciated.

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NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. **BIBLIOGRAPHIC DATA SHEET** *(See instructions)*	1. PUBLICATION OR REPORT NO. NBSIR 84-2910	2. Performing Organ. Report No.	3. Publication Date August 1984

4. TITLE AND SUBTITLE

Field Evaluation of SPT Energy, Equipment, and Methods in Japan Compared with the SPT in the United States

5. AUTHOR(S)

William D. Kovacs; Lawrence A. SAlomone

6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

10. SUPPLEMENTARY NOTES

[ ] Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

Field energy measurements on Japanese drill rigs were made during the performance of the Standard Penetration Test to document the difference between Japanese and present U.S. Practice. A total of 78 Standard Penetration Tests were performed using 19 different testing conditions (equipment and operators). Over 2000 data points are reported.

Results from this investigation show that the average value for ER_i (the ratio of the energy passing through the drill rod to the theoretical free-fall energy) using Japanese equipment and operators is 68 percent with a standard deviation of 9.6 percent.Considering only energy and sampler effects, the ratio of U.S. blow counts to Japanese blow counts (N_{US}/N_J) is 0.98 (variation between 0.72 and 1.80) when the cathead and rope method was used as the hammer release mechanism and using ER_{US} equals 55 percent and ER_J equals to 67.4 percent. When the Tombi method (free-fall) was used, the ratio of N_{US}/N_J is 1.17 (variation between 0.86 and 2.15) when ER_{US} equals 55 percent and ER_J equals 80.4 percent. It was found that the Japanese use bottom discharge drill bits and an SPT sampler with a constant inside diameter of 1-3/8 in (35 mm) in contrast to U.S. procedures and equipment. A shape factor to account for differences in sampler is presented.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

Energy measurement; field testing; in situ testing; liquefaction potential; soil mechanics; SPT; Standard Penetration Test.

13. AVAILABILITY

[X] Unlimited
[ ] For Official Distribution. Do Not Release to NTIS
[ ] Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
[X] Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

72

15. Price

$10.00