LIQUEFACTION POTENTIAL AND THE INTERNATIONAL SPT

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SUMMARY

Field experimental evidence suggests that the energy delivered to the drill rods in the Standard Penetration Test (SPT) varies substantially in the United States and across international borders. The problem is further complicated because much of the data base used in liquefaction potential evaluation is international. This paper discusses the present situation in SPT testing and recommends methods by which variability of test results can be reduced and a common international basis can be provided for the interpretation of test results.

INTRODUCTION

The latest design chart for liquefaction potential (Ref. 1) utilizes SPT data from various countries. The data base is composed from blow counts obtained from a wide variety of equipment and operating procedures. Because of this variety of equipment and procedures, it can be expected that the energy delivered to the sampler also varied between the drill rigs which were used to acquire the liquefaction data base. The energy transmitted through the drill rods in the SPT test is transferred by the impact of the 140-pound (63.5 kg) hammer falling 30 inches (762 mm) through an anvil (or knocking head). The blow count is inversely proportional to the energy passing through the drill rods (Ref. 2), and when there is a variation in that energy, there is a corresponding variation in blow counts recorded for identical field conditions. Kovacs et al., 1983, (Ref. 3), documented that the average energy passing through the drill rods in 43 measurements on 18 different types of U.S. drill rigs varied between approximately 40 to 80 percent of the specified potential ("standard") energy for safety (type) hammers. For donut (type) hammers, 13 energy data points are available from 7

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different drill rig models, with a range from 30 to 75 percent of the standard energy. When all 56 energy values are averaged (published information to date, 1983), the average energy or energy ratio expressed as a percent of the standard energy [4200 in-lbs (475 J)] becomes approximately 55 percent. Several authors have used this or similar numbers in the past. They include: Schmertmann and Smith, 1977, (Ref. 4), in calibrating the Florida Department of Transportation drill rigs (50% was used); Robertson et al., 1982, (Ref. 5), in correcting blow counts when comparing q_c/N ratios from the cone penetration test; and, more recently, Kavazanjian et al., 1983, (Ref. 6), when they used the wave equation to correct blow counts to a 55 percent energy ratio for their hammer efficiency. If the 55 percent energy ratio would be found uniformly in all drill rods, then a similar profile of N values with depth would be found regardless of the drill rig, equipment, procedures, and operator used to perform the SPT. This paper attempts to document the energy variation and proposes an approach that could be used to mitigate the effects of the variation in SPT equipment and procedures used to perform the Standard Penetration Test.

EVIDENCE OF ENERGY VARIATION

In the United States, the American Society for Testing and Materials (ASTM) Standard D 1586-67 (re-approved 1974) is used for the Standard Penetration Test. The current standard states in paragraph 2.3, "... and a guide permitting a free fall of 30 inches (0.76 m). Special precautions shall be taken to ensure that the energy of the falling weight is not reduced by friction between the drive weight and the guides."

To conform with a "free-fall" approach, the British, for example, have been using a mechanical self-tripping mechanism to ensure complete free fall. Based on 23 tests by Decker, 1983, (Ref. 7), an average energy ratio of 55 percent was found for the Pilcon (trip) hammer. In the same study, based on 10 data points, an average free-fall energy ratio of 76 percent was found for the Japanese donut (type) hammer as specified in Japanese Industrial Standard A 1219-1961 (re-affirmed 1976). When the Japanese hammer is used with a cathead and rope, it is estimated that the energy passing through the drill rods would be approximately 65 percent, or about 1.2 to 1.3 times higher than that in average U.S. practice. The estimated difference between U.S. and Japanese average energy ratios is thought to be caused by the more efficient energy transfer through the anvil of the Japanese design, as well as a higher impact velocity resulting from the Japanese type B cathead design where the concave cathead is used. (Field tests in Japan are planned for the Fall of 1983 to evaluate the energy in the Japanese drill rods for comparison with U.S. practice.) No other published information is presently (October 1983) available on the energy ratio obtained in countries outside the U.S.

POTENTIAL EFFECT OF LARGER ENERGY RATIOS OUTSIDE THE U.S. ON THE PRESENT LIQUEFACTION DATA BASE

If the ratio of ENERGY JAPAN/ENERGY U.S. is about 1.2 to 1.3, say 1.25, then, all other variables being equal, the ratio of SPT blow counts would be the inverse, or N U.S./N JAPAN ≃ 1.25. Thus, to correct a Japanese blow count to U.S. average energy, it would be necessary to multiply the Japanese blow count by 1.25. As a result, each Japanese data point used to generate the design chart would move accordingly, making the present suggested design curve unconservative. In practice, this difference may be diminished by the difference between U.S. and Japanese samplers. U.S. samplers have an ASTM-specified 1/16-inch recess for a liner which is not normally used. The absence of the liner results in reduced friction. Japanese samplers do not have the 1/16-inch recess.

PROPOSED DESIGN METHOD INCORPORATING SPT ENERGY MEASUREMENTS

The present suggested design approach [Seed et al. (Ref. 1] incorporates the following steps to use the correlation of SPT blow counts with the performance of sand deposits in previous earthquakes:

1. Evaluation of the cyclic stress ratio for a vertical effective overburden pressure of one ton per square foot (~100 kPa).

2. Evaluation of the modified penetration resistance corrected to an overburden pressure of one ton per square foot (~100 kPa).

The present method to evaluate the modified penetration resistance is given by equation 1 [Seed et al. (Ref. 1)]:

$$N_1 = C_N \cdot N \qquad (1)$$

where C_N = A function of the effective overburden pressure at the depth where the penetration test was conducted.

N = The field SPT blow count.

N_1 = Modified penetration resistance corrected to an effective overburden pressure of 1 ton per square foot (~100 kPa).

To account for the variation in energy to be expected throughout the world from different drill rigs, equipment, procedures and operators, it is proposed to further normalize the present modified blow count, N_1, by the following method:

Let ER_i = the average energy ratio measured during the evaluation of the field blow count, N. Procedures for measuring ER_i have been discussed elsewhere [Kovacs et al. (Ref. 3)]. Further, assume a reference energy level of 55 percent. Then, equation (1) becomes:

$$N_1 = C_N \cdot N \cdot \frac{ER_i}{55} \cdot C_s \qquad (2)$$

where C_s is a coefficient to correct for difference in sampler configuration (data on C_s will be taken in Japan in Fall, 1983), normalizing the blow count for effective overburden pressure, as well as for variations in energy in the drill rods and sampler configuration used during the performance of the SPT. This equation assumes that the test results are normalized to 55 percent of the standard energy and to a specific sampler configuration (say U.S. samplers without a liner). By international agreement, test results could also be normalized to some other basic condition.

RECOMMENDED INTERIM SPT PROCEDURES IN ABSENCE OF CALIBRATION BY EQUATION (2)

To reduce the variability of SPT results, the following procedures are recommended for evaluating the liquefaction potential of important structures:

a. Safety (type) hammer with AW drill rod stem with an available stroke of at lease 35 inches (889 mm).

b. Two turns of new rope around the cathead.

c. Use of an 8-inch (203 mm), clean, shiny cathead.

d. AW (parallel wall) drill rod.

e. Rotary drilling with mud.

f. Upward deflecting wash drilling bit.

g. Blow count rate of 30 to 40 blows/minute.

h. An SPT sampler with no liners [I.D. of 1.5 inches (38.1 mm)].

i. The fluid level in the bore hole should be at all times higher than the groundwater level. This can be accomplished by requiring that the surface of the drilling mud be at the top of the bore hole at all times.

j. A 2-inch (50 mm) colored band shall be permanently marked on the hammer guide pipe [from 28 to 30 inches (711-762 mm) above the anvil] to help the operator produce an average 30-inch fall height.

[Procedures c, e, f and h are based on findings by Schmertmann, 1977, (Ref. 4).] These recommendations are discussed in detail by Kovacs et al., 1983, (Ref. 3).

CONCLUSIONS

On the basis of available data, it appears that for the same soil conditions SPT blow counts performed by U.S. equipment and procedures could on the average exceed Japanese blow counts by about 25 percent. This difference may be diminished by the difference between U.S. and Japanese SPT samplers. It is proposed to adjust SPT blow counts to account for the energy efficiency of the system and for the sampler used. Until such an adjustment is adopted for the profession, it is suggested to follow procedures outlined in this paper in addition to those stipulated in ASTM D 1586-67, in order to reduce the variability of results.

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