THE ASSESSMENT OF LIQUEFACTION SUSCEPTIBILITY USING THE SEISMIC CONE PENETROMETER

by

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INTRODUCTION

A new "hybrid" test method which incorporates cone penetration testing and in-situ downhole shear wave velocity measurements has been developed at UBC. This paper describes how this equipment works, its relative advantages and disadvantages compared to the SPT and outlines its use for liquefaction assessment.

ADVANTAGES AND DISADVANTAGES OF CPT AND SPT

To avoid the problems of obtaining undisturbed samples of sandy soils many engineers prefer to adopt the field correlation approach using in-situ testing. The most commonly used in-situ test for correlation to field liquefaction properties of saturated cohesionless soils has been the SPT. However, a major disadvantage of the SPT is its lack of repeatability. One major source of error is the variation in energy delivered to the drill rods. UBC measurements of energy delivered by 18 Vancouver area drill rigs are shown in Figure 1. A large variation in N-value may be obtained at a particular site solely due to difference in hammer types. It has, therefore, been suggested that N-values should be corrected to an average energy value. Robertson et al. (1983) suggest 55 % and Seed and De Alba (1986) suggest 60 % of the theoretical maximum.

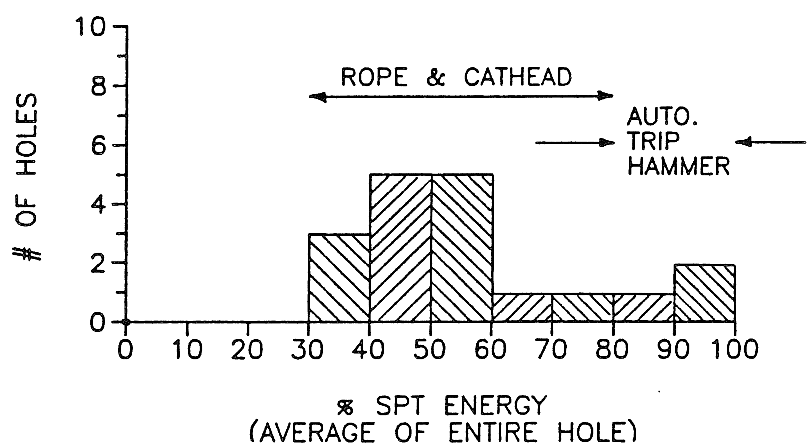

Figure 1. Average Energy Values Measured At The Top Of The Drill Rods For Vancouver Area Drill Rigs

Use of the CPT overcomes many of the disadvantages of the SPT. CPT testing is accurate, repeatable and gives a continuous record. In addition it now offers the ability to measure additional parameters including pore pressure and shear wave velocity. The use of CPT and shear wave velocity measurements for liquefaction assessment is discussed in the next sections.

INTERPRETATION OF CPT FOR LIQUEFACTION ASSESSMENT

Most experience to date in in-situ testing for liquefaction assessment of sandy soils has involved relating the SPT N-value to the cyclic shear resistance. In order that the SPT experience can be used with CPT data, correlations between end bearing (qc) and N-value have been developed. One such correlation is shown in Figure 2.

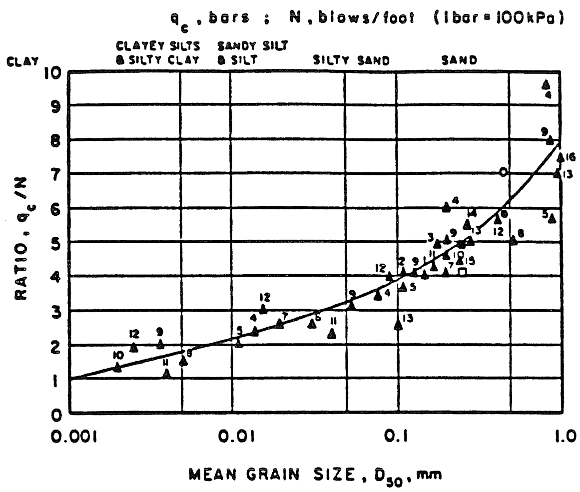

Figure 2. Variation of qc/N Ratio With Mean Grain Size (after Robertson,Campanella and Wightman (1983))

Recent experience with the CPT has been combined with the SPT data through the qc/N correlations and with laboratory data to derive relationships between liquefaction resistance and cone bearing. Cone bearing values must be modified for overburden stress. Robertson and Campanella's (1985) correlation is shown in Figure 3.

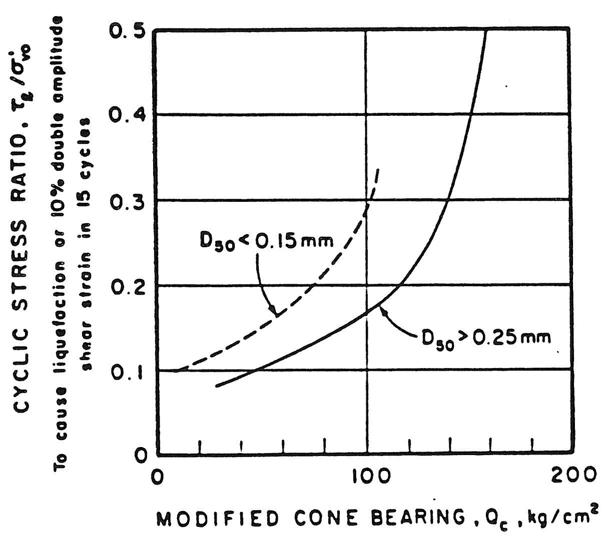

Figure 3. Correlation Between Liquefaction Resistance Under Level Ground Conditions And Cone Penetration Resistance For Sands And Silty Sands (after Robertson and Campanella (1985))

Other methods to interpret CPT data include those of Zhou (1980), Seed et al. (1983) , Seed and De Alba (1986), and Olsen (1984).

COMPACTION CONTROL

Commonly, liquefiable soils are improved by compaction. The CPT is ideal for compaction control. Contract specifications generally require a minimum end bearing and may make allowance for fine grained soils by excluding soils having friction ratios greater than a specified value. The accuracy of the test reduces the uncertainty often experienced with the SPT. Figure 4 shows an example of before and after compaction profiles where the after compaction profiles have been performed in the centroid of vibrocompaction columns.

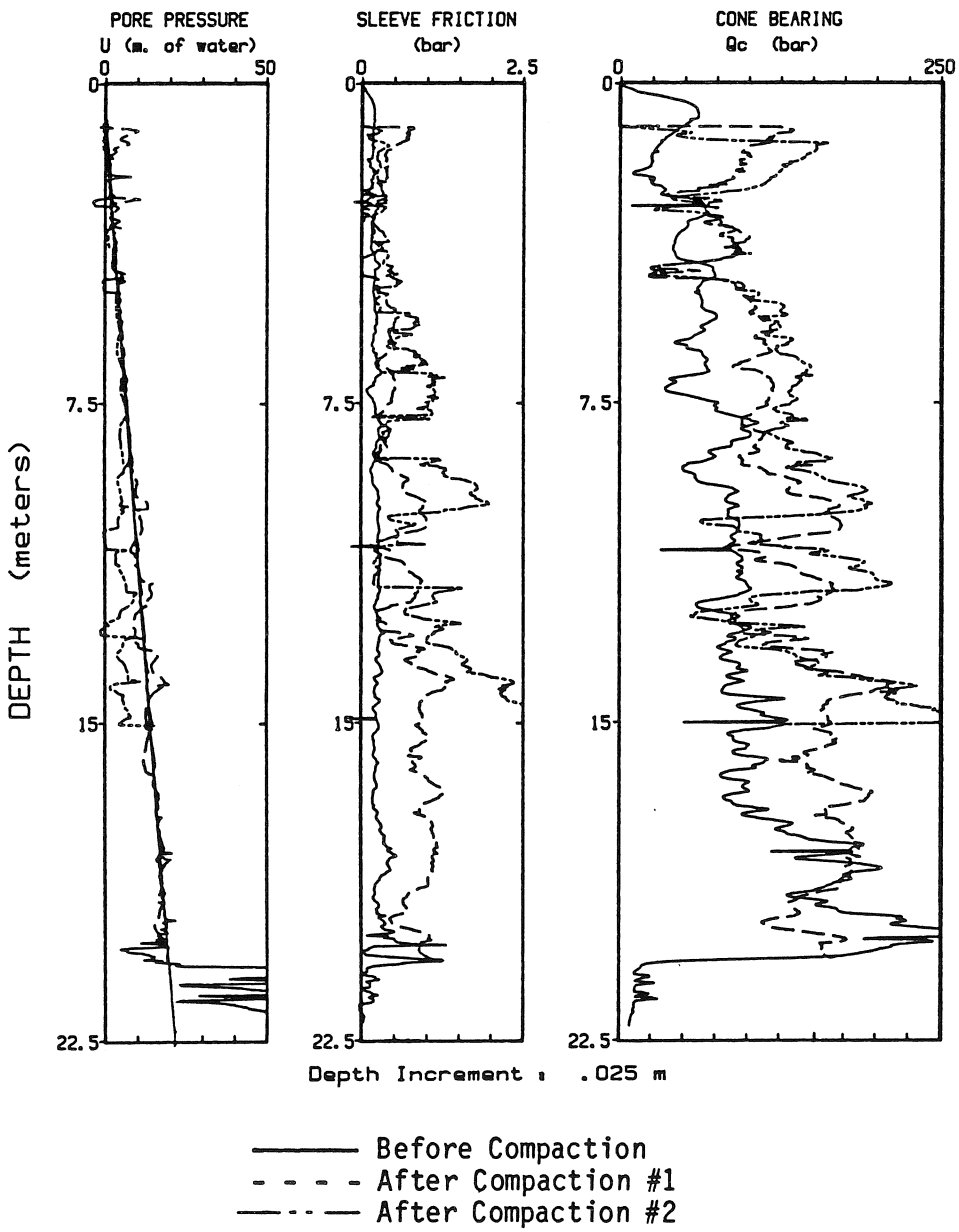

Figure 4. Before and After Compaction CPT Profiles (Richmond, B.C.)

SHEAR WAVE VELOCITY MEASUREMENTS

Shear wave velocity measurements can be incorporated into the CPT by adding a velocity transducer or accelerometer into the cone and by using an appropriate high speed data acquisition system. Shear waves are most commonly generated by striking a weighted plank source with a sledge hammer. By striking the plank on alternate sides the shear waves can be polarized, which assists in their identification.

An interval technique may be used to calculate wave velocities. Typically, readings are taken at 1 metre intervals when the CPT is stopped for the addition of rods. Arrival times or crossover times can be used in the manner shown in Figure 5 to calculate velocity. Research conducted at UBC, Rice (1984), found that the crossover times were easier to define and resulted in accurate shear wave velocities.

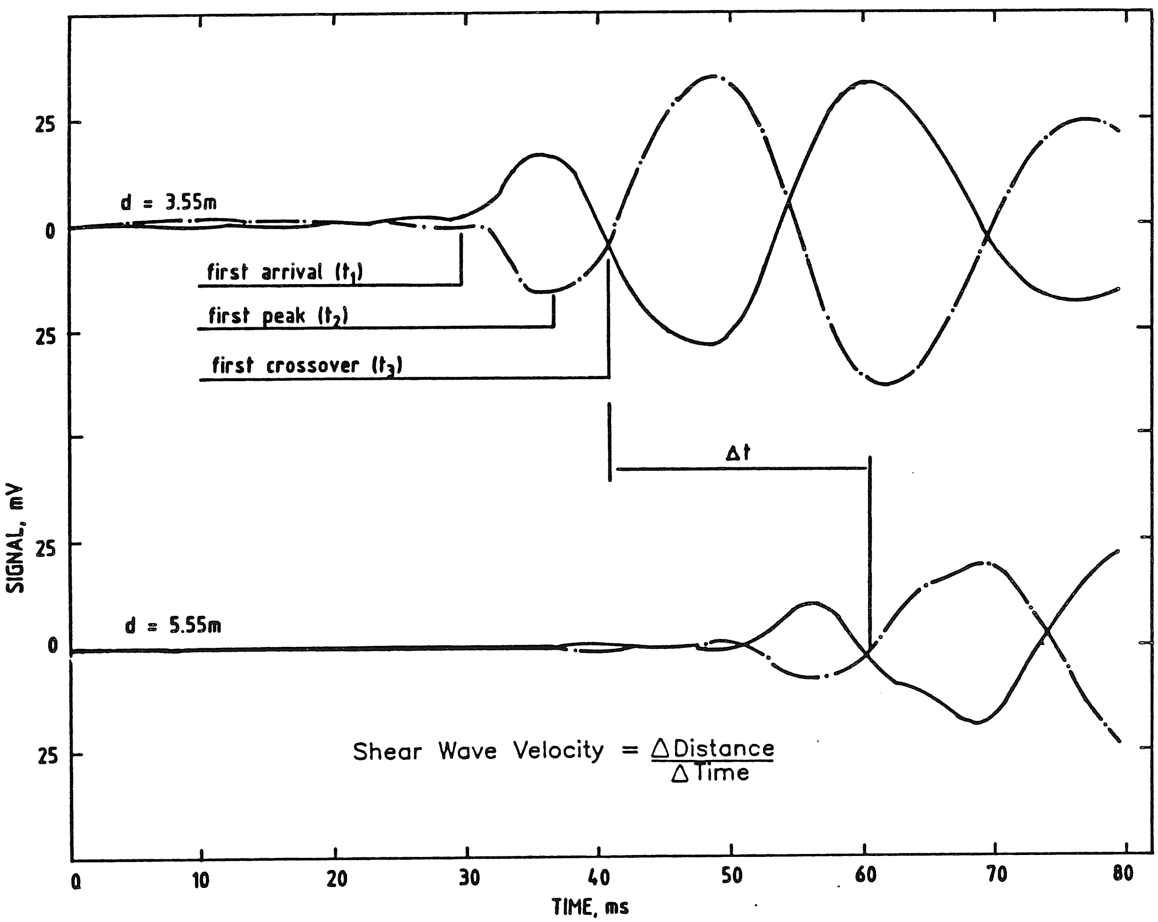

Figure 5. Typical Polarized Wave Arrivals and Velocity Calculation Procedure

INTERPRETATION OF VELOCIITY MEASUREMENTS FOR LIQUEFACTION ASSESSMENT

Shear wave velocity can be converted to the small strain shear modulus using elastic theory: $G_{max} = \rho V_s^2$.

The shear wave velocity can be used in two ways to assess liquefaction susceptibility:

i) Values of Gmax are essential input to computer programs used in detailed liquefaction assessment;

ii) Correlations exist between shear wave velocity and the development of pore pressure during earthquake loading,(Dobry et al. (1981)).

USE OF P-WAVE VELOCITY MEASUREMENTS

Combined with an appropriate source, the seismic CPT can also be used to calculate the P wave or compression wave velocity. It is known that the degree of saturation has an important effect on the liquefaction potential of saturated sands. As the P wave velocity is highly dependent on the degree of saturation it is probably the best indicator of the degree of saturation.

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