Proceedings ISC-2 on Geotechnical and Geophysical Site Characterization, Viana da Fonseca & Mayne (eds.)
© 2004 Millpress, Rotterdam, ISBN 90 5966 009 9

New de-coupled shear wave source for the SCPT test

L. Areias, W. Haegeman & W.F. Van Impe
Department of Civil Engineering, University of Ghent, Belgium

Keywords: seismic source, shear waves, SCPT test, de-coupling

ABSTRACT: This paper describes a new seismic source to generate high-energy shear (S) wave signals for the seismic cone penetration (SCPT) test. The new source uses an innovative load de-coupling system that significantly reduces the effective overall mass of the source. Test results using the new source are presented and compared with results from a conventional source. The results show that S wave signals generated with the new system contain 3 to 4 times more energy than signals produced with existing conventional methods.

1 INTRODUCTION

The static cone penetration (CPT) test has been modified to measure seismic wave velocity in soils (Robertson et al, 1986). The SCPT test measures shear (V_s) and compression (V_p) wave velocities, from which the maximum shear (G_o) and elasticity (E_d) moduli are derived. G_o and E_d are related to the density of the medium (ρ) and Poisson's ratio (ν) by:

$$G_o = \rho\, V_s^2 \tag{1}$$

$$G_o = \frac{E_d}{2(1+\nu)} \tag{2}$$

Values of V_s and V_p are further related to ν by the equation:

$$\nu = \frac{\left(\frac{V_s}{V_p}\right)^2 - 0.5}{\left(\frac{V_s}{V_p}\right)^2 - 1.0} \tag{3}$$

SCPT tests are performed using a CPT truck. This allows both geotechnical and seismic data to be obtained simultaneously, in the same test. It also makes the SCPT test efficient and cost effective.

2 WAVE GENERATION

Shear waves in SCPT tests are generated at the surface using a beam-and-hammer type source. The beam or base plate is weighted down using the weight of the CPT truck to obtain firm and secure coupling with the ground. The weight of the CPT truck is placed directly on the beam. This method of weighting the beam is here called *coupled* loading.

The ends of the beam are struck horizontally to produce pairs of predominantly polarized S waves. Hitting the beam vertically generates predominantly compression (P) waves.

Generated seismic waves are detected by geophones (or accelerometers) installed in the cone. Typically, an array of 3 orthogonally-oriented geophones is located in the cone's housing, close to the cone's tip. Two of the geophones are installed horizontally to record the S waves. The third geophone is positioned vertically to capture the P signals.

3 OPTIMUM COUPLING FOR S WAVES

The amplitude of surface-generated S waves in the SCPT test partly depends on the level of coupling stress (Areias et al., 1999). Coupling stress is here defined as the normal static stress between the base plate and the ground.

Test results by the authors indicate that relatively low coupling stresses are required to generate maximum amplitude S wave signals, for given impact energies (Figure 1). These tests were performed using a specially designed 24 kg adjustable mechanical swing hammer to produce controllable and repeatable energy impacts. The results shown were obtained with 15° and 45° impact swing angles. The difference in impact energy between the two swing angles is approximately double.

It is common practice to weigh down the source using the weight of the CPT truck. Since a CPT truck can weigh up to 20 tons, a wide range of coupling stresses can be generated on the beam when it is loaded in this manner. As a result, SCPTs are being performed using a variety of coupling stresses. This can significantly reduce the energy and quality of the signals.

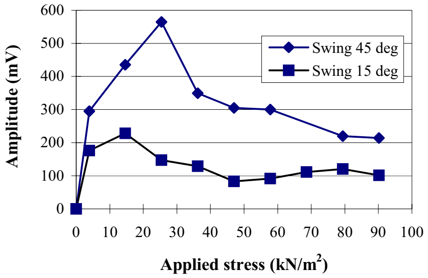

Figure 1. Variation of S wave amplitude with coupling stress in coupled-load tests (Areias et al., 1999)

4 MODELING OF S WAVE SOURCE

The base plate is modeled as a suspended simple beam to study its physical interaction with the ground. Assuming full elastic conditions during impact, and that the collision between the hammer and the beam is one dimensional, we can write the following expressions relating mass and velocity of the source system. From conservation of momentum we have:

$$m_h V_{hi} + m_b V_{bi} = m_h V_{hf} + m_b V_{bf} \qquad (4)$$

Where:
m_h = mass of sledgehammer
V_{hi} = initial velocity of sledgehammer
m_b = mass of impact beam (base plate)
V_{bi} = initial velocity of impact beam
V_{hf} = final velocity of sledgehammer
V_{bf} = final velocity of impact beam

Since the collision is elastic, kinetic energy is conserved, by definition, and we obtain:

$$\frac{1}{2} m_h V_{hi}^2 + \frac{1}{2} m_b V_{bi}^2 = \frac{1}{2} m_h V_{hf}^2 + \frac{1}{2} m_b V_{bf}^2 \qquad (5)$$

Rearranging (4) and (5), and noting that the base plate is initially at rest before collision, we can write the following expression for V_{bf}:

$$V_{bf} = \left(\frac{2m_h}{m_h + m_b} \right) V_{hi} \qquad (6)$$

Equation (6) is only valid for a suspended beam, as noted. When the beam contacts the ground, a ground force (F_g) will act between the beam and the ground to resist movement of the beam. It is generally assumed that F_g is proportional to the particle velocity (V_x) of the ground just below the beam (Van der Veen et al., 1999; Miller and Pursey, 1954) and is expressed by:

$$F_g = V_x \; Z_{rad} \qquad (7)$$

Where:
Z_{rad} = radiation impedance

Radiation impedance is a measure of the resistance of the ground to motion when a force is applied (Miller and Pursey, 1954). This represents the interaction of the source with the ground.

Assuming a purely physical interaction and perfect coupling between the beam and the ground, the particle velocity just below the beam will be equal to that of the beam itself, i.e. V_x=V_{bf}.

Noting that the mass of the base plate is much greater than that of the hammer (m_b>>m_h), we can deduce from (6) and (7) that the ground force is inversely proportional to the mass of the plate, for given hammer impacts.

5 NEW S WAVE SEISMIC SOURCE

Conventional sources are weighted down by weights coupled directly to the impact beam, as shown in Figure 2. According to equations (6) and (7), this type of loading increases the overall mass of the beam-hammer system and should lead to a decrease in F_g and S wave energy.

A new seismic source system was designed to verify the results expressed by (6) and (7). Specifically, a new hold-down-load system was developed to reduce the overall mass of the source. This was done by isolating applied hold-down loads from the base plate.

The new system, herein referred to as *de-coupled* source system, uses a system of rollers (or other friction-reducing mechanism) to effectively decouple applied loads form the base plate along the horizontal direction. A simplified design of this system is shown in Figure 3.

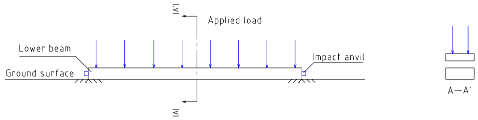

Figure 2. Typical conventional coupled source

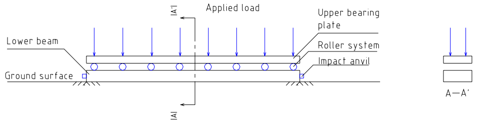

Figure 3. Simplified design of de-coupling mechanism for new seismic source

6 TEST RESULTS

Field tests were performed using both conventional and the new de-coupled seismic-source systems. These tests were carried out to evaluate the performance of the new de-coupled source system. The tests were performed using the adjustable mechanical swing hammer previously described to produce controllable and repeatable energy impacts. The tests were further performed using a solid steel beam as base plate.

Typical test results, showing amplitude as a function of applied coupling stress, are presented in Figures 4 and 5. Figure 4 shows results obtained using relatively low energy hammer impacts produced using 15^o swings. Figure 5 presents results obtained using hammer swing angles of 45^o for higher energy impact.

The results show that the amplitudes of S signals generated with the new de-coupled source are 3 to 4 times greater than those obtained using a conventional source. The tests also confirm the results of the physical modeling study, which suggested that F_g could be significantly increased by lowering the mass of the beam.

7 CONCLUSIONS

A newly designed de-coupled seismic source system for the SCPT test method has been briefly described. The new source uses an innovative load de-coupling system that effectively reduces the overall mass of the source to increase S wave energy.

Field tests show that amplitudes of S signals generated with the new system are 3 to 4 times greater than those obtained using conventional sources. The new system should improve SCPT testing in general by increasing S wave signal-to-noise ratios, extending test depth and enhancing accuracy of measured signals.

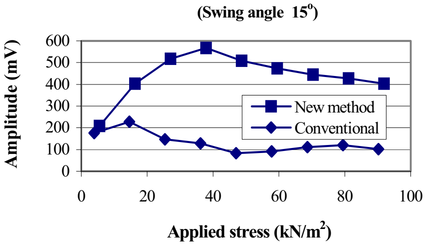

Figure 4. Comparison between new and conventional sources for hammer swings of 15^o

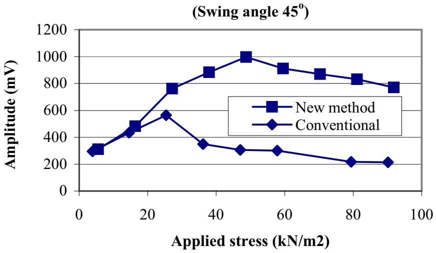

Figure 5. Comparison between new and conventional sources for hammer swings of 45^o

ACKNOWLEDGEMENTS

The authors are grateful to Dr J. Brouwer for his helpful suggestions at the early stages of this research.

REFERENCES

Areias, Lou, W.F. Van Impe and W. Haegeman (1999), 'Variation of Shear Wave Energy with Coupling Stress in the SCPT method', *European Journal of Environmental and Engineering Geophysics*, Volume 4, Number 1, pp. 87-95.

Miller, D.F. and H. Pursey (1954), 'Field and Radiation Impedance of Mechanical Radiators on a Free Surface of a Semi-Infinite Isotropic Solid', *Proceedings of the Royal Society A 223*, pp.521-541.

Robertson, P.K., R.G. Campanella, D. Gillespie and A. Rice (1986). Seismic CPT to measure in-situ shear wave velocity, *Journal of Geotechnical Engineering,* Volume 112, nr. 8, pp. 791-803.

Van der Veen, Michiel, Jan Brouwer and Klaus Helbig (1999), 'Weighted Sum Method for Calculating Ground Force: an Evaluation by Using a Portable Vibrator System', *Geophysical Prospecting*, 47, pp. 251-267.