Discussion Session 1.2 / Séance de Discussion 1.2

Ground property characterization by in-situ tests

Caractérisation des propriétés des sols par essais in-situ

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ABSTRACT: Enhanced in-situ testing involves the utilization of complementary techniques during the geotechnical site characterization programs of natural soils and rocks. Investigations that combine both geotechnical penetration testing with geophysical methods can optimize the types and amount of information gathered for the exploration. Tests can be done separately or in combination. Of increasing value, the measurement of shear wave velocity has been shown significant and relevant to static and dynamic geotechnical problems and should be adopted as a routine measurement in practice.

1 INTRODUCTION

Geotechnical site investigation involves the site-specific study of natural soil and rock materials that are quite complex in their response to loading. These geomaterials exhibit highly nonlinear stress-strain-strength characteristics that are affected by drainage conditions, rate effects, anisotropy, thixotropy, ageing, overconsolidation, cementation, and additional variables that are often not quantified in routine explorations. It is generally insufficient to quantify their behavior simply by taking drive samples and counting the blows of hollow tube that is pounded into the ground. More measurements are needed to adequately describe the complicated response and engineering parameters that characterize the geomaterials. Perhaps there are too many parameters and properties that can be quantified. Nevertheless, as geotechnical engineering moves into the 21st century, the profession must move forward and adopt new technologies to complement and supplement the routine drilling & sampling methods that have been the staple of the practice.

High quality numerical measurements for assessing soils are available from various in-situ testing devices including the electronic cone penetrometer, flat plate dilatometer, piezocone, pressuremeter, and electrovane, as well as a variety of nondestructive and often non-invasive geophysical methods including resistivity surveys, electromagnetic imaging, ground penetrating radar, magnetometer, and the measurement of mechanical waves (crosshole, downhole, surface waves, suspension logging, refraction, and reflection). These measurements can provide additional numerical values to the strength, stiffness, and flow characteristics of natural geomaterials in addition to the necessary drilling and sampling practices for visual examination and laboratory testing program. Of particular interest today is the need to provide different input parameters for 2-d and 3-d numerical simulation modeling of the site, such as finite elements, finite differences, boundary elements, and discrete elements.

2 ENHANCED IN-SITU TESTING

For the 15th international conference, the themes selected by TC 16 included presentations on the following topics:

1. Enhanced in-situ geotechnical site characterization using hybrid tests provide multiple types of subsurface data: Combined geotechnical penetration + geophysics = seismic piezocone test (SCPTu) and seismic flat dilatometer (SDMT), as well as the cone pressuremeter (CPMT) and newly-developed dilatocone (DMTCPT). Added modules for resistivity, time-domain reflectometry, pH levels, dielectric, and permittivity would add value and direction to improved explorations. More measurements in a single sounding are prudent in order to optimize and maximize the number and quality of measurements taken. Perhaps a return to the self-boring pressuremeter test (SBPMT) with 4 measurements obtained at each depth may be in order for modern geotechnics.

2. The importance of small-strain measurements (V_S) and relevance to static & dynamic problems during both drained and undrained soil behavior should be noted and utilized in geotechnical practice. This aspect is well-addressed in the Pre-Failure Deformation of Geomaterials conferences that were held in Sapporo (1995), London (1997), and Torino (1999), as well as the recent TC 29 publication (2001).

3. Reliability & Variability Issues of In-Situ Measurements. Repeatability of soundings using CPTu and related derivatives. Site variability vs. errors incurred in in-situ measurements. Expected COV for the qt, fs, u1, u2, and Vs measurements. Use of Class I, II, and III penetrometers for determination of reliable soil properties & parameters vs. geostratigraphic logging (after Lunne, Robertson, & Powell, 1997).

3 MEASURED SOIL STIFFNESS FOR DEFORMATIONS

The ability to measure the shear wave velocity (V_S) constitutes the most important advancement in settlement (deformation) predictions since the advent of the CPT. The small-strain shear modulus (G_0) is obtained from the shear wave and represents a fundamental stiffness of the geomaterial. Simply stated:

$$G_0 = \rho_T V_S^2$$

where ρ_T = total mass density of the geomaterial.

Seismic CPTs obtain the measurement of downhole shear wave velocity for very little marginal cost compared to standard CPT testing. Methods using spectral analysis of surface waves (SASW) give an attractive alternative for obtaining V_S profiles with depth. Ideally, a combination study with the SBPMT would be beneficial to determine the amount of distortion necessary to apply to a hyperbolic model (e.g., Fahey, 1998). Perhaps additional work with the DMT and research DMT devices that measure the entire pressure-deflection of the dilatometer membrane can show application for collection of intermediate strain level data.

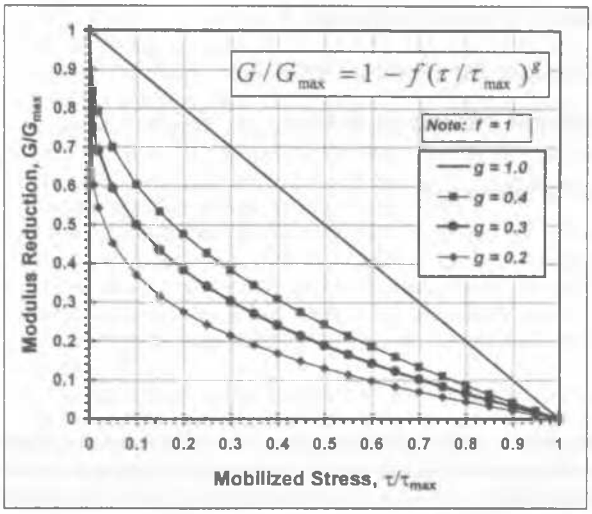

Figure SS-1. Modulus Reduction Factors versus Mobilized Strength from Modified Hyperbola (after Fahey 1998).

4 STRAIN DEPENDENT DEFORMATION PROPERTIES

Results from geophysical seismic tests can be useful in routine geotechnical explorations. Some of the aspects here include: (1) determination of soil layering and boundaries by refracted P- and S-waves; (2) correlation between wave velocities and other geotechnical parameters; and (3) direct use of vibration measurement data for geotechnical design (modulus). In this regard, the reduction of the initial tangent modulus or small-strain stiffness obtained from the seismic measurements needs to be reduced to an appropriate value corresponding to the relevant strains (or mobilized stress level).

Modulus reduction schemes have been sought using empirical expressions, theoretical formulations, and numerical simulations. Detailed calibrations using field performance monitoring and meticulous laboratory investigations with highly-instrumented triaxial stress path testing have shown the relevance and importance in G_0 for static and dynamic analyses. The monotonic curve degrades at a faster rate than that associated with cyclic loading. Very active research programs in Europe and Asia have now interrelated the laboratory and field measurements, as detailed in Shibuya et al. (1994), Jardine, et al. (1997), Jamiolkowski, et al. (1999), and Tatsuoka et al. (2001). The reduction from small- to intermediate- to large-strains is a unified approach to the development of entire stress-strain-strength-time curves for geomaterials and improved understanding for predictions and analysis.

5 CHARACTERIZATION OF SOILS AND ROCKS

The applications of the small-strain stiffness and modulus degradation schemes are applicable to soils and rocks. In fact, shear wave velocity measurements are one of the few tests that can span the entire range of soil particles for characterization, from colloids to clays, silts, sands, gravels, to cobbles, boulders, to weathered and intact rocks. The modulus reduction curves are quite varied as bonding, cementation, yield surfaces, and frictional envelopes are all affecting the induced stress paths and effective stress states of the material (Tatsuoka, et al. 1999). An expedient means to softening the small-strain modulus to stress levels relevant to working load levels of full-scale structures is afforded through a modified hyperbola (Fahey 1998) of the form:

$$G/G_{max} = 1 - f(\tau/\tau_{max})^g$$

Where f and g are fitting parameters. For a first approximation and preliminary design of foundations and structures on unstructured, uncemented, and "well-behaved" soils, the values of f = 1 and g = 0.3 for low-sensitivity clays and quartzitic sands (Mayne 2001). Figure SS-1 shows the types of curves generated by this modified hyperbola in relation to a simple hyperbolic form (f = 1 and g = 1). Note that the mobilized stress (τ/τ_{max}) is the reciprocal of FS or factor of safety. For detailed analyses and numerical efforts, monotonic torsional shear tests and/or static triaxial tests with instrumented local strain measurements on high-quality samples should be conducted to determine the true variation of modulus with level of strain (and stress).

6 REFERENCES

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