Current Trends and Challenges in In-Situ Testing

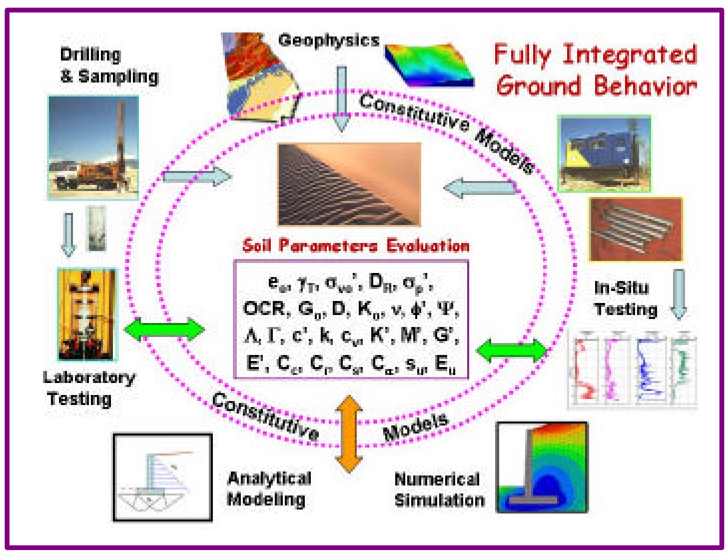
Paul W. Mayne, PhD, P.E., Professor

Civil & Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0355

ABSTRACT

In complement to conventional drilling and sampling operations for site exploration, direct measurements from in-situ tests are increasingly used to derive soil properties and parameters for geotechnical analysis and design. The interpretations of initial geostatic stress state and stress-strain-strength-flow characteristics are calibrated with laboratory test data obtained from high-quality samples, but at high costs. Considerable gains in efficiency, economy, and time are to be obtained by in-situ devices, including cone, dilatometer, pressuremeter, and vane. Current interpretation procedures use a hybrid of empirical, analytical, experimental, and/or numerical methods, whereas a comprehensive-integrated numerical simulation of all field tests is needed. Of particular interest, the seismic piezocone test with dissipation phases (SCPTù) offers an optimal collection of five separate readings (q_t, f_s, u_b, t_{50}, and V_s) of soil behavior within a single sounding, and therefore should be adopted for routine geotechnical investigations.

INTRODUCTION



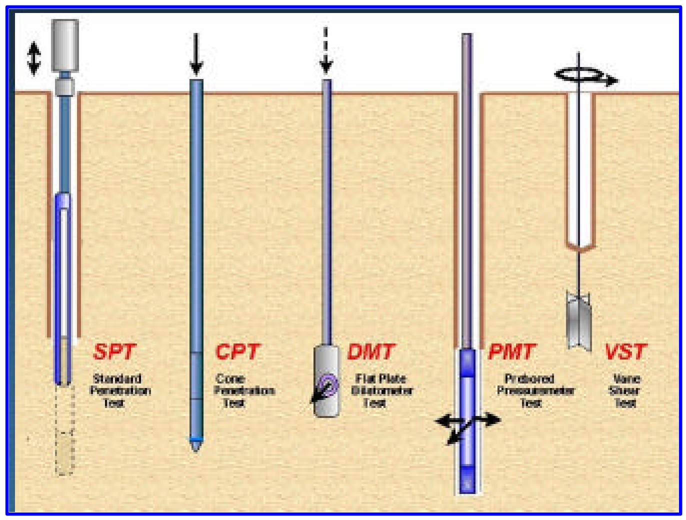
Soils are extremely complex four-dimensional (x, y, z, t) materials in their constituent behavior, having varied mineralogical and geological constituents, three-phase particulate components, and logarithmic size distributions. In addition, the aspects of initial stress state, nonlinear stiffness, strength, anisotropy, permeability, drainage characteristics, and rheological behavior provide a formidable task for all those charged with conducting a meaningful site investigation. Yet, these geomaterials must be characterized adequately before any new foundation, embankment, roadway, earthen dam, tunnel, or excavation is constructed on or within the ground.

A thorough investigation of a particular geologic formation should consider the initial anisotropic-preconsolidated geostatic stress state and nonlinear stress-strain-strength behavior, drainage paths, and flow behavior under dry/saturated, drained/undrained, as well as partially-saturated conditions. Since *Mother Nature* has bequeathed such a wide diversity of particulates, mineralogies, fabrics, cementitious agents, and packing arrangements, a fully global numerical model which integrates all aspects of the ground may be difficult to formulate in the near future. At present, the best practice is to employ a combination of drilling, sampling, and in-situ field testing during geotechnical site exploration.

INTEGRATED GROUND BEHAVIOR

To implement an integrated approach to characterizing ground behavior, all aspects of the natural geomaterials must be included, including the geologic setting, stress state, and a complete suite of soil parameters and properties. The site exploration program should involve geologic field mapping and utilization of geophysical surveys (ground penetrating radar, electromagnetic conductivity, resistivity), careful drilling & sampling to obtain high-quality specimens, material indices, laboratory testing, and complementary sets of in-situ tests.

A good number of different in-situ tests are available for site investigation (Robertson, *Canadian Geot. J.* 1986), with the most common being the standard penetration test (SPT), cone penetration (CPT), piezocone (CPTu), flat plate dilatometer (DMT), pressuremeter (PMT), and vane shear test (VST). For measurements of mechanical waves, especially the shear wave, the geophysical methods include: crosshole (CHT), downhole (DHT), seismic reflection (SRFL), and spectral analysis of surface waves (SASW), as well as recent improvements in seismic refraction (SRFR).



For most geotechnical projects, the full suite of drilling & sampling, laboratory, and in-situ testing cannot be implemented because of time and costs. Depending upon the nature of geologic setting and level of the proposed construction, perhaps only a select number of lab tests (i.e., index, consolidation, direct shear, triaxial, permeability) and one or two of the basic in-situ tests (i.e., SPT, CPT, CPTu, DMT, PMT, VST) can be implemented. For these tests, the tasks of soil parameter interpretation can be handled by empirical, closed-form analytical, numerical, or experimental methods. In many cases, an assortment of these different methods are adopted in practical applications.

SEISMIC PIEZOCONE

In terms of expediency and economy, the seismic piezocone (SCPTù) provides an optimal means to profile the geostratigraphy and stress-strain-strength-flow soil properties of the ground, as five independent readings are measured with depth at the same location: q_t, f_s, u_b, t_{50}, and V_s. The test is a hybrid of cone penetration and downhole geophysics to maximize the amount and types of subsurface data collected during site investigation (Robertson, et al., *J. Geotech Engrg.* 1986). At an advance rate of 20 mm/s, continuous readings of tip stress (q_t), sleeve friction (f_s), and penetration porewater pressure at the shoulder ($u_2 = u_b$) are recorded. At 1-m intervals, a new cone rod is added and the temporary stop allows for two additional measurements: (a) porewater pressure decay with time, *Du(time)*; and (b) arrival time (Δt_s) of a surface-generated shear wave via a horizontal geophone(s) embedded in the probe. The dissipations are usually taken to 50% consolidation (time = t_{50}) and the distance over time gives the shear wave velocity

(V_s). Thus, the full suite of readings allows multiple direct and independent assessments of the probing of the ground ranging from nondestructive strains to peak failure via measurements of stress, shear, pressure, time, and velocity. A similar packaging has been developed to create a seismic flat plate dilatometer that can obtain five readings with depth: q_D, p_0, p_1, t_{flex}, and V_s.

Recent European & Asian research focuses have shifted towards the behavior of soils at small-strains to detail the initial stiffness and deformational properties of the ground (e.g., Burland, *Canadian Geotech. J.* 1989; Tatsuoka, et al., *ICSMGE* 1997). Here, special triaxial equipment with local internal strain gages coupled with torsional shear results on high-quality sampling methods provided the clues. Series of test comparisons with resonant column equipment were made (e.g., Georgiannou, et al., *ECSMFE* 1991). Notably, the well-known initial tangent shear modulus (G_{dyn}) that was required in problems involving soil dynamics (e.g., Hardin & Drnevich, *ASCE JSMFD* 1972) became recognized as the initial stiffness for all stress-strain curves, notably for static monotonic loading and unloading, as well as dynamic loading. Today, the small-strain shear modulus from nondestructive measurements can be realized as $G_0 = G_{max} = G_{dyn} = \rho_T V_s^2$, where ρ_T = total soil mass density and V_s = shear wave velocity. This fundamental stiffness is relevant as an initial stress state, whereby: e_0 = initial void ratio, σ_{v0} = initial vertical overburden stress, u_0= hydrostatic porewater pressure, $K_0 = \sigma_{ho}'/\sigma_{vo}'$ = lateral geostatic stress coefficient, and G_0 = initial shear modulus.