Robertson's Remarks

- Shearwave Veolcity for Settlement Calculations-

In this 'Remarks', I would like to discuss the application of shear wave velocity for settlement calculations. A major advantage of the seismic Cone Penetration Test (CPT) is the additional measurement of shear wave velocity, V_s. The shear wave velocity is measured using a downhole technique during pauses in the CPT resulting in a continuous profile of V_s along with the cone tip resistance, q_c, sleeve friction, f_s, and pore pressure, u. Elastic theory states that the small strain shear modulus, $G_o = \rho V_s^2$, where ρ is the mass density of the soil ($\rho = \gamma/g$). Hence, the addition of shear wave velocity during the CPT provides a direct measure of soil stiffness. The small strain shear modulus (G_o) represents the elastic stiffness of the soil at shear strains (γ) less than about 10^{-4} percent. In cases where the settlement is controlled by shearing of the soil and not the long term consolidation/compression (i.e. cohesionless (sand & gravel) soils, stiff overconsolidated fine grained soils and short term loading of soft clays) the shear modulus can be used to estimate settlements.

Application to engineering problems requires that the small strain modulus be softened to the appropriate strain level. The softening can be carried out assuming a modified hyperbola where the shear modulus (G_s) at any degree of loading is $G_s = G_o (1 – (q/q_{ult})^{0.3})$, where q/q_{ult} is the degree of loading in terms of the applied footing pressure, q and the ultimate bearing capacity, q_{ult}. Elastic theory also states that the Young's modulus, E_s is linked to G_s, by $E_s = 2(1+\nu)G_s$, where ν is the Poisson's ratio, which ranges from 0.1 to 0.3 for most soils and is typically 0.25. Hence, the Young's modulus for any applied load is $E_s = 2.5\ G_o(1 – (q/q_{ult})^{0.3})$.

Since settlement is a function of degree of loading, it is possible to calculate the full load-settlement curve for any shallow foundation using $s = q\ B\ i_c\ /\ E_s$, where s is the settlement of a footing of width B under loading q and i_c is the influence coefficient depending on the footing size and shape.

In general, for most well designed shallow foundations, $\boldsymbol{E_s \approx G_o}$. In variable ground, the appropriate value of G_o (and hence, E_s) should be based on the average value of V_s under the footing over a depth of $2B$ below the footing. This approach has been validated by research on full size footings (Mayne, 2003).

The seismic CPT can provide an excellent means to estimate the settlement of shallow foundations in many ground conditions under a wide range of loading conditions. Hence, the seismic CPT provides excellent stratigraphic profiling (via, q_c, f_s and u), excellent estimates of soil strength (via q_c) and excellent estimates of soil stiffness (via V_s) in a continuous, cost effective manner. The shear wave velocity can also be used directly as an independent means for the evaluation of liquefaction potential.

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