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Manual on Estimating Soil Properties for Foundation Design

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clay can affect the N value greatly, as shown in Figure 4-51. Apparently, the penetration process causes temporary excess pore water stresses which reduce the effective stresses in the vicinity of the sampler, thereby resulting in an apparently lower N value.

However, for clays within a given geology, a reasonable correlation might be expected between s_u and N. Figure 4-52 indicates this behavior over a wide range of N values where the same drilling equipment, SPT procedure, and consistent reference strength (UU triaxial) were employed. For these data, the reported regression is given by:

$$s_u/p_a = 0.29\ N^{0.72} \tag{4-60}$$

This equation tends to predict s_u/p_a on the high side of the relationships shown in Figure 4-50.

Correlations with CPT q_c Value

The theoretical relationship for the cone tip resistance in clay is given by:

$$q_c = N_k\ s_u + \sigma_{vo} \tag{4-61}$$

in which q_c = cone tip resistance, σ_{vo} = total overburden stress, and N_k = cone bearing factor. The application of classical plasticity theory to this bearing capacity problem suggests N_k on the order of 9 for a general shear model. Cavity

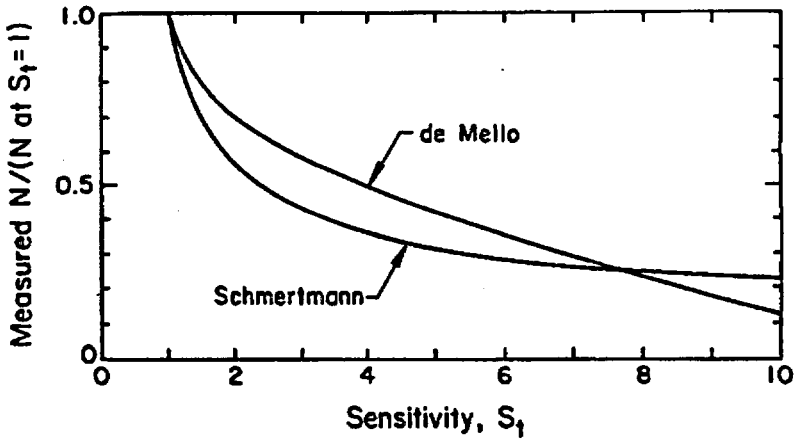

Figure 4-51. Apparent Decrease of N with Increasing Sensitivity

Source: Schmertmann (14), p. 66.

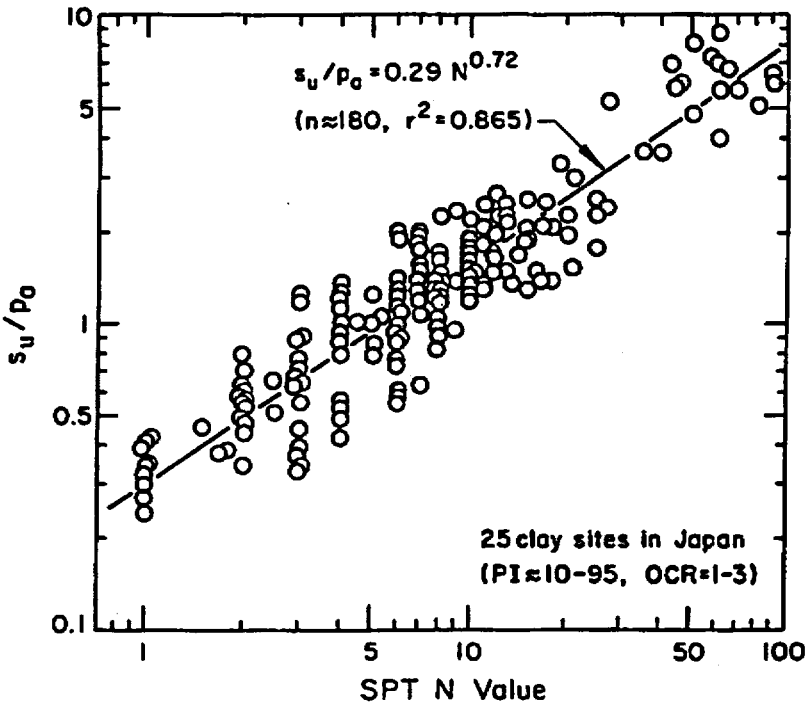

Figure 4-52. Relationship Between s_u and SPT N Value

Source: Hara, et al. (72), p. 9.

expansion theories give N_k increasing in the range of 7 to 13 for increasing values of rigidity index ($I_r = G/s_u$, with G = shear modulus). Steady penetration theory provides a narrow range for N_k between 14 and 18 for a wide range of I_r.

With the various uncertainties in choosing appropriate theoretical models, it is not surprising that N_k usually is determined empirically by calibrating CPT data with a known measured value of s_u. The range of values of N_k back-calculated from CPT data is presented in Figure 4-53. This wide range of N_k values must be scrutinized for several reasons: (1) inconsistent reference strengths, (2) mixing of different type cones (electric and mechanical), and (3) need for correction of q_c for pore water stress effects (Appendix B). These factors can change N_k dramatically.

The importance of correcting q_c for pore water stress effects has been discussed previously and is illustrated by Figure 4-54 for two piezocones with different area ratios. The corrected cone tip resistance (q_T) can be obtained only by use of piezocones with porous elements located behind the tip. Consequently, the large scatter observed in empirical determinations of N_k may result, in part, from use of

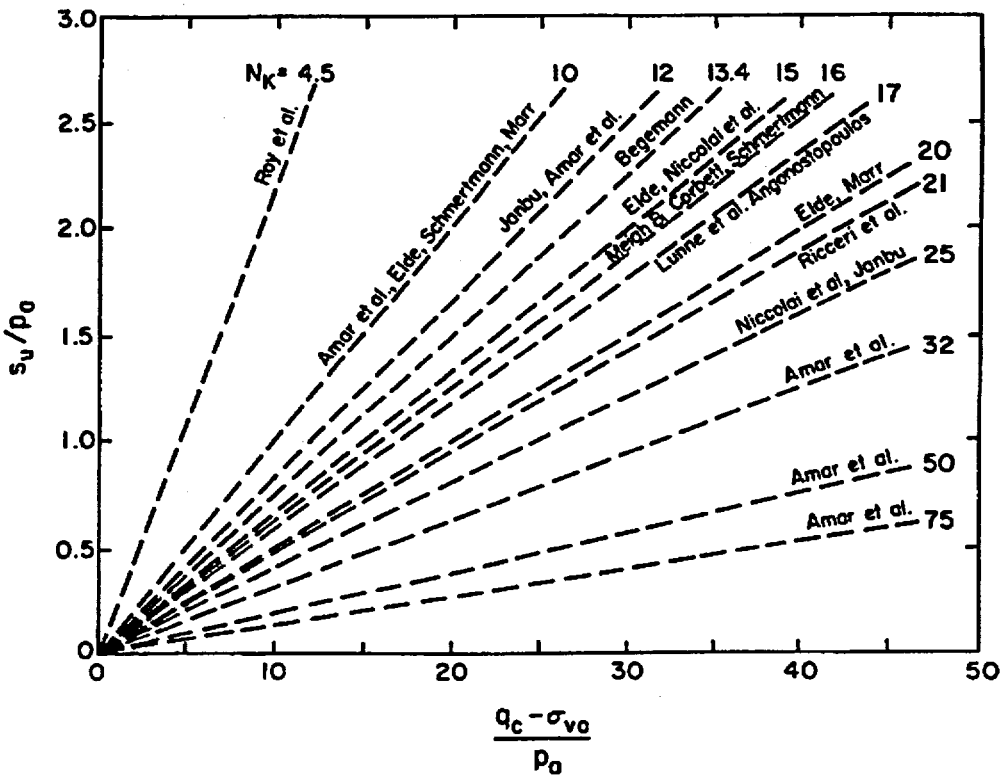

Figure 4-53. Reported Range of N_k Factors from CPT Data

Source: Djoenaidi (71), p. 5-83.

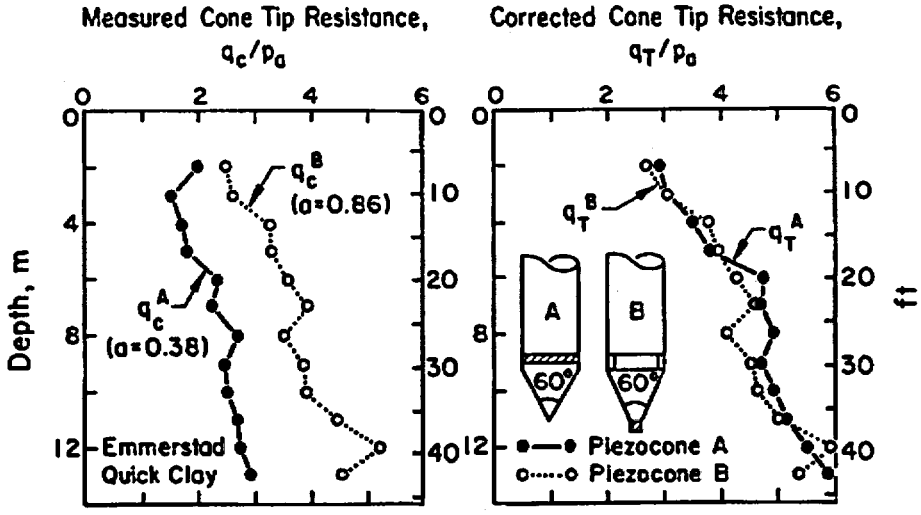

Figure 4-54. Effect of Pore Water Stress on Cone Tip Resistance

Source: Aas, et al. (67), p. 19.

an uncorrected q_c.

The value of N_k ideally should be determined experimentally by comparison with a consistent reference strength. Often, the field VST is used as the reference. In this regard, it is important to recall that the VST requires a correction for s_u in itself. Early correlations (e.g., Battaglio, et al., 73) for N_k using uncorrected VST data suggested a trend for N_k in terms of the plasticity index (PI). However, upon later re-analysis of the same data using the corrected VST strength [$\mu\ s_u$(VST)], N_k apparently was independent of PI.

Subsequent studies by Keaveny and Mitchell (74) and Konrad and Law (75) have demonstrated that Vesić's cavity expansion theory (76) provides a reasonable estimate for N_k, as given below:

$$N_k = 2.57 + 1.33\ (\ln I_r + 1) \qquad (4\text{-}62)$$

Keaveny and Mitchell suggest using CK_oUC triaxial compression tests to evaluate I_r, while Konrad and Law recommend using the self-boring pressuremeter test.

Recent theoretical developments (Houlsby and Teh, 77) suggest that more refined procedures for determining s_u from the CPT may be appropriate. However, these models currently require a number of parameters that are difficult to determine. Further testing in the future may allow convenient determination of these parameters and a better estimation of s_u.

Correlations with CPTU Results

The piezocone penetration test (CPTU) permits determination of s_u from the corrected cone tip resistance (q_T), as described previously, and also allows for a separate estimate of s_u from the pore water stress measurement. Research on this subject (e.g., Robertson, et al., 78) has suggested the following:

$$s_u = \Delta u / N_{\Delta u} \qquad (4\text{-}63)$$

in which Δu = measured excess pore water stress ($u_m - u_o$) and $N_{\Delta u}$ = pore water stress ratio, which may be estimated from A_f and either the PI or rigidity index, as shown in Figure 4-55. Alternative recommendations by Konrad and Law (75) suggest a more complex relationship, including a number of parameters which are somewhat difficult to evaluate.