Development of a Chart for Preliminary Assessments in Pavement Design Using Some In Situ Soil Parameters

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Much information has been generated from in situ soil tests conducted over the last two decades. Because of variations in mechanical and procedural details and the intended use of these tests, the information can be too specific, fragmented, or sometimes difficult to interpret. There is a need to gather and present this information on a common basis. The work presented in this paper introduces a practical approach that aims to address part of this need and to incorporate some in situ parameters in preliminary estimations for pavement design. The results of the study are preliminary. Nevertheless, the impact is twofold: the study is an initial effort to gather and present various in situ test information on a common basis and introduces direct utility of some in situ test parameters in broad estimation of bearing parameters in pavement design. The results of a great number of tests have been used to establish correlations between some in situ tests, and also to establish correlations between in situ parameters and soil properties. The well-known correlations are those between cone penetration (CPT) and standard penetration (SPT) tests, and between the soil type and the cone penetration, dilatometer (DMT), and pressuremeter (PMT) parameters. Four such correlations were incorporated into an existing design chart that included approximate interrelationships between soil classification, modulus of subgrade reaction, and California bearing ratio (CBR). The new correlations (SPT, CPT, PMT) were based on soil classification.

A chart showing approximate interrelationships between soil classification and bearing values has been satisfactorily utilized for rapid estimation of design parameters for foundations of pavements (*1*). After an estimate of soil classification has been made, the chart can be very useful in arriving at approximate values for bearing and modulus of subgrade reaction in pavement design. The advent of in situ testing methods, and the rapid and often systematic manner with which soil data are obtained using these methods, have resulted in the accumulation of new information. The incorporation of this information into the currently used chart is timely.

Variations in the mechanics and procedures of the in situ tests, as well as problems encountered in data interpretation, can make it difficult to correlate parameters obtained through these tests. The existing correlations are often based on soil index properties and soil classification (*2–5*). The various in situ test parameters are used to predict the shear strength, stiffness, bearing capacity, or settlement of foundation soils. Some of these parameters, or mathematical combinations of different measurements in a particular test, are also used as indices or coefficients with which to classify soils and predict overconsolidation ratio, consistency, or relative density. In this paper, such indices or parameters (*6–10*) were studied to establish the graphical correlations between them on the basis of soil classification.

The updated chart is basically intended as a quick reference with which to make reliable first approximations of the California bearing ratio (CBR) and modulus of subgrade reaction (k) based on the measured in situ properties. The chart can be used to classify the soil or to estimate in situ properties once soil classification has been performed in the laboratory. Another important feature of the new chart is that it presents a comparison of soil classification predictions by three in situ tests.

BACKGROUND

Some In Situ Tests

Results of three tests are utilized in this study: the cone penetration test (CPT), the standard penetration test (SPT), and the self-boring pressuremeter test (SBPMT or PAF).

Standard Penetration Testing

SPT (ASTM D1587) is one of the oldest sounding methods. It was developed in 1927. The blow count per foot (N) is correlated with the relative density, the unit weight, and the angle of internal friction of soils. N is also used to estimate the allowable bearing capacity (q_a) and elastic modulus (E_s) of shallow foundations. Some correlations of SPT result in large scatter, and therefore the use of SPT alone is not generally recommended for design purposes. A well-known correlation of SPT and CPT is q_c/N versus mean grain size (D_{50}) (*6*), shown in Figure 1. A more recent study presents the relationship between normalized CPT parameters and the SPT blow count (N), as shown in Figure 2 (*3*). The basic advantages of using SPT are that the procedure has been widely used for a long time, resulting in a significant buildup of experience, and it is relatively simple and economical.

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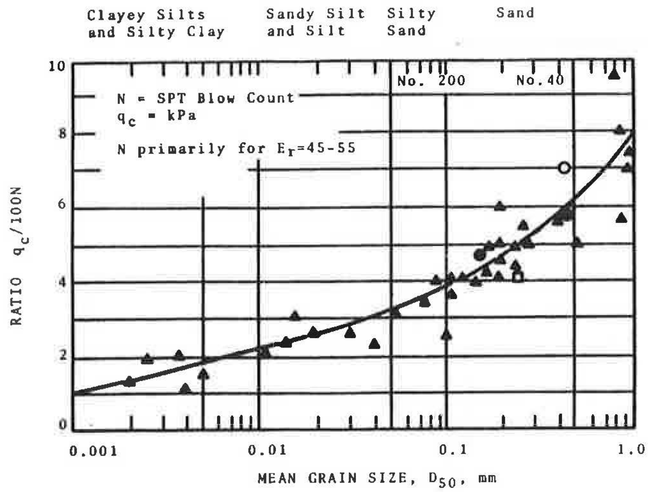

FIGURE 1 Relationship between grain size (D_{50}) and q_c/100 *N* ratio (*6*). (E_r = standard energy ratio; q_c = cone tip bearing.)

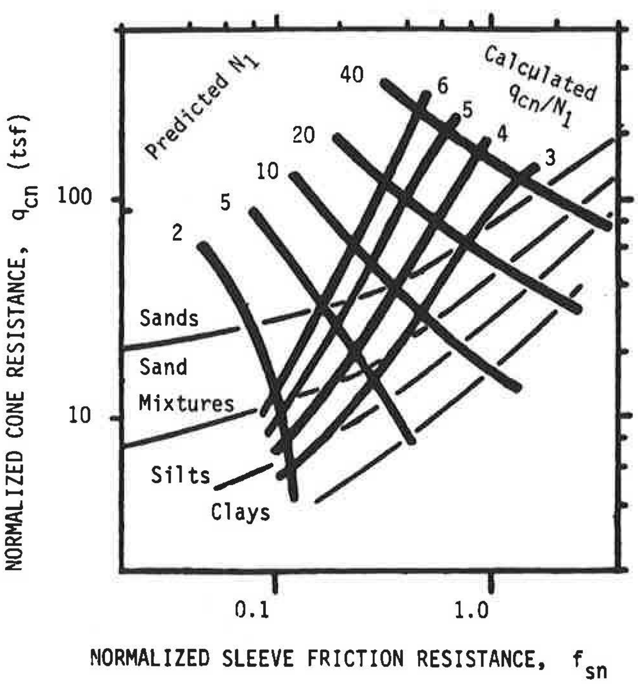

FIGURE 2 Normalized SPT blow count per foot versus normalized CPT parameters (*3*).

Cone Penetration Testing

Cone penetration testing (ASTM D3441) has become a versatile and reliable tool for continuous subsurface investigation. There are various types of cone penetrometers available (e.g., mechanical, electric, and seismic cones, and piezocones), and use has widened significantly over the years. The accumulation of information has resulted in the development of soil classification charts, as shown in Figures 2 and 3 (*7*). CPT data has much less scatter than SPT data, and its interpretation is more reliable; it is therefore recommended for foundation design purposes. The parameters obtained from CPT tests—tip bearing (q_c), sleeve friction (f_s), excess pore pressure (Δu) with piezocone, and various mathematical combinations of these parameters—have been correlated with undrained shear strength (s_u), ultimate bearing of shallow and deep foundations, the internal friction angle for sands, the elastic modulus (E_s), the overconsolidation ratio (OCR), and soil classification (*2,4,5,11–18*).

Pressuremeter Testing

The borehole pressuremeter test has been widely used in France since it was first developed by Ménard in 1956 (*19–22*). Discussions of pressuremeter tests have been published by a number of investigators (*21,23,24*). The self-boring pressuremeter was developed to overcome some of the problems associated with the borehole PMT (i.e., borehole preparation and soil expansion) in the mid 1970s in France and England (*19,25*). Both of these pressuremeter tests have gained considerable usage, both in research and in practice, in the United States in recent years (*26–29*). The parameters obtained from PMT are used to predict bearing capacity and settlement of shallow foundations, and bearing capacity and axial and lateral displacement of piles. Some of the soil parameters obtained through PMT are undrained shear strength (s_u), coefficient of lateral earth pressure at rest (K_0) and tangent (E) and secant (E_s) soil moduli. The soil identification coefficient (β), given in Equation 9, and net pressure applied at 20-percent strain (p_{20}), are used to classify soils, as shown in Figure 4.

Bearing Values in Design of Pavements and Their Foundations

The existing design chart that provides approximate interrelationships of soil classification and bearing values includes ASTM soil classification (USC ASTM D2487); AASHTO soil classification (AASHTO M145); FAA soil classification, resistance value (R) (ASTM D2844, AASHTO T190); modulus of subgrade reaction (k) (Portland Cement Association); bearing value (ASTM D1195, D1196, or AASHTO T221, T222); and California bearing ratio (CBR) (ASTM D1883, AASHTO T193). This chart (*1*) has been used by practitioners to arrive at approximate numbers for the bearing values once a soil classification has been obtained through laboratory analysis. The chart is a rapid and reliable means of obtaining preliminary estimates of the required values of bearing.

The new chart presented here incorporates two soil classification systems (ASTM and AASHTO), the modulus of subgrade reaction, and the CBR. This is both for reasons of simplicity, and because of the existence of correlations between these parameters and the in situ parameters. These correlations were used in preparation and also in verification of the chart. The modulus of subgrade reaction (k) is used in concrete pavement design. The thickness of the pavement can be determined through a design chart based on k and single axle load. The modulus of subgrade reaction is defined as the pressure per unit deformation of the subgrade. In the field, the determination of k for concrete pavement design is generally done for a deformation of 0.05 in., using a 30-in.-diameter plate. CBR is a punching shear test developed by the California Division of Highways. It is used by the U.S. Army

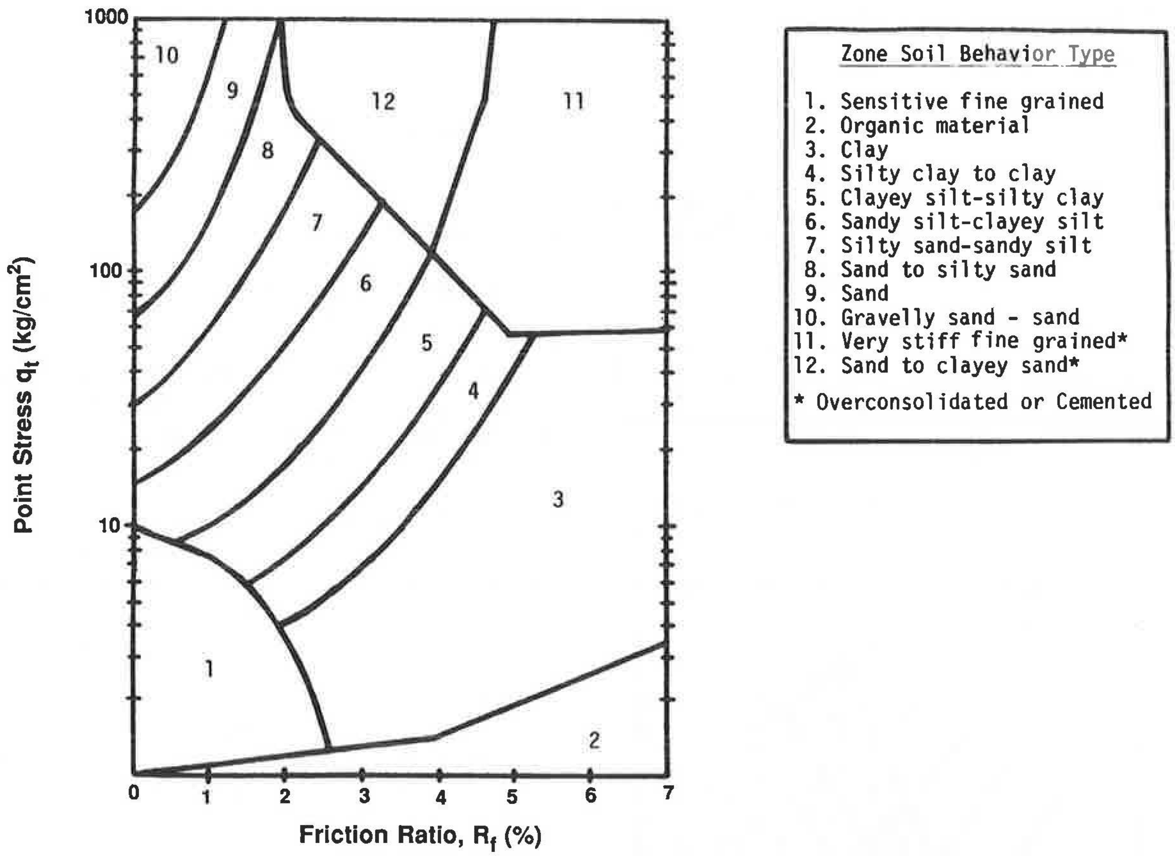

FIGURE 3 Soil classification system from CPT data (*7*).

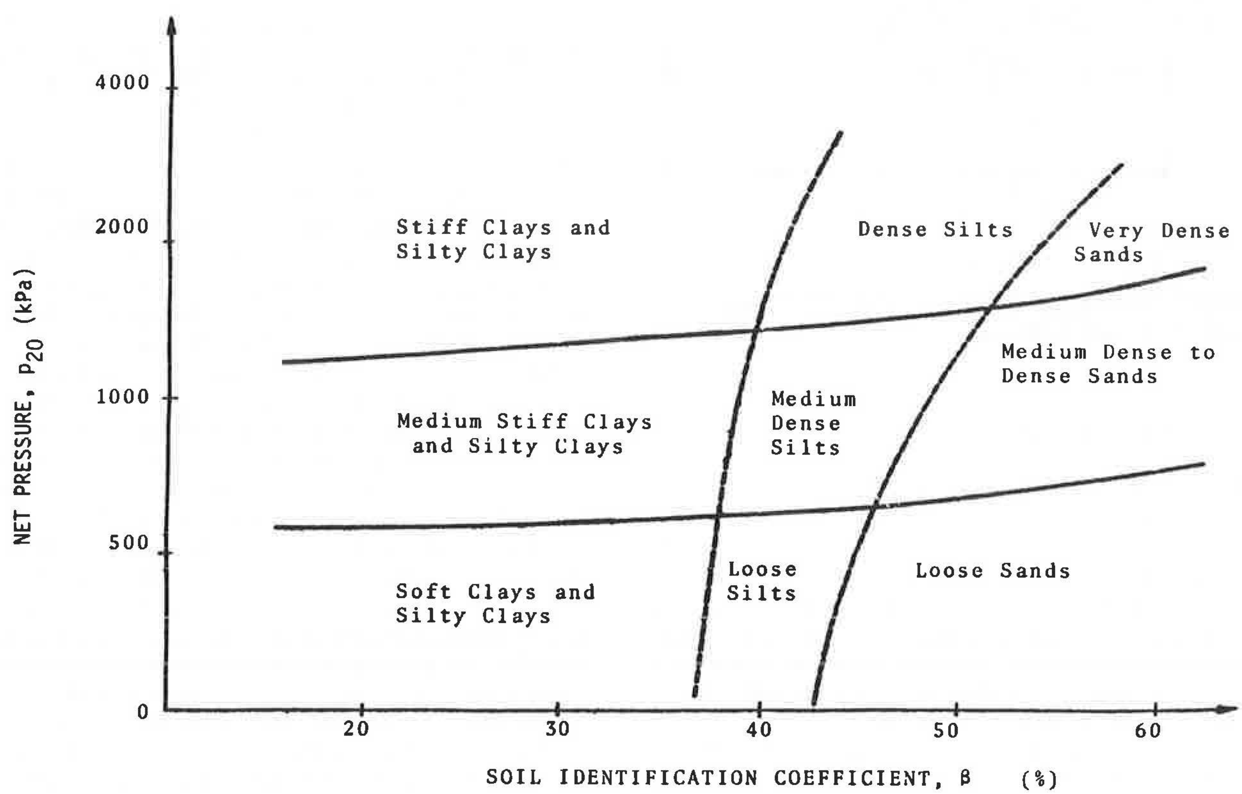

FIGURE 4 Soil classification based on self-boring pressuremeter data (*9*).

Corps of Engineers and by a number of highway departments to evaluate the bearing value of subgrade soils.

DEVELOPMENT OF THE NEW CHART

A number of existing correlations were used in the development of the new chart. These correlations are presented with their references in Table 1. The intent was neither to disprove nor to verify these correlations but rather to use them as tools to develop the chart. The reader and possible users of the chart should be fully aware that these correlations and assumptions may or may not prove to be valid for certain soil types as new information and data bases develop. In such cases, modification of the chart would be warranted. Furthermore, it should be noted that it is important to verify the predictions and estimations made from this chart through field testing to ensure reliability and consistency. The work presented here does not include such verification.

Figure 5 shows the new chart. The CPT-SPT correlation was done using the $q_c/100N$-versus-D_{50} relationship shown in Figure 1. The following equations were employed to arrive at approximate allowable bearing capacity values using the k and CBR values from the new chart (refer to Table 1 for references):

$$X_1 = q_c/q_a \quad (1)$$

$$q_c = 280 \times \text{CBR} \quad (2)$$

$$k = 40 \times \text{SF} \times q_a \quad (3)$$

$$k = 40 \times 280 \times \text{SF} \times \text{CBR}/X_1 \ (\text{kPa/m}) \quad (4)$$

Using a safety factor (SF) of 3, which is an appropriate value for shallow foundations, the X_1 values were evaluated. The chart description of soil type with respect to these values was found as follows:

$$q_c/10 < q_a < q_c/12 \qquad \text{sand} \quad (5)$$

$$q_c/6 < q_a < q_c/10 \qquad \text{clayey silt, silt, sandy silt} \quad (6)$$

$$q_c/4 < q_a < q_c/6 \qquad \text{clay} \quad (7)$$

These values agree with the estimates given for shallow foundations with SF = 3 in cohesive and cohesionless soils, as summarized by Sanglerat (*12*). Using Equations 1 and 3 and the $q_c/100N_{55}$ ratio from the new chart, approximate N values were estimated for different k values corresponding to different soil types. The resulting equations were:

$$X_2 = q_c/100N \quad (8)$$

$$N = (k \times X_1)/(40 \times 3 \times 100 \times X_2) \quad (9)$$

The calculated N values varied from 14 for well-graded sands to 2 for high-plasticity clays. These values were recognized to be somewhat on the low side. Backcalculating q_c using these N values resulted in good agreement with the q_c values that are shown in Figure 3 to correspond to various types of soils.

Figure 6 shows the variation of q_c/N with R_f/N calculated from Figure 2, and superimposed on it is the trend of the same data estimated from the chart. The chart values were found from the approximate relation between $q_c/100N_{55}$ and $q_c/100R_f$. As observed from Figure 6, the values obtained from the chart that correspond to q_c/N values of 3, 4, 5, and 6 (where q_c is in tsf) fall well within the limits seen for soil classification ranges that correspond to the chart classification.

Finally, Figure 4 was utilized to correlate SBPMT parameters. The soil identification coefficient (β) was directly related to the ASTM soil classification with respect to clays, silts, and sands. The following expression and the ratios presented in Table 2 (*20*) were utilized to arrive at the G_{p0}/p_{20} correlation shown in the new chart.

$$\beta = (p_{20} - p_5)/p_{20} \quad (9)$$

$$G_{p5} = p_5/0.05 \quad (10)$$

When using Table 2, average values of clay and sand ratios were calculated for silts.

TABLE 1 CORRELATIONS USED IN DEVELOPMENT OF THE NEW CHART FOR PAVEMENT DESIGN

Correlation	Reference
$q_c/100\,N$ vs. D_{50} (Figure 1)	Robertson et al., 1983 (*6*)
q_{cn} vs. f_{sn} and N (Figure 2)	Olsen and Farr, 1986 (*3*)
q_t vs. R_f (Figure 3)	Robertson et al., 1986 (*7*)
p_{20} vs. β (Figure 4)	Becue et al., 1986 (*9*)
G_{p0}/G_{p2} and G_{p2}/G_{p5} (Table 2) ratios vs. soil type	Jesequel and Le Mehaute, 1979 (*20*)
$q_c = 280 \times \text{CBR}$ (kPa)	Scala, 1954 (*30*); Sanglerat, 1972 (*12*)
$k = 40 \times \text{SF} \times q_a$ (kN/m² · m)	Bowles, 1988 (*31*)
$q_a = q_c/X_1$	Sanglerat, 1972 (*12*)

NOTE: q_c = cone tip bearing; N = SPT blow count/ft; D_{50} = mean grain size; q_{cn} = normalized cone tip bearing; f_{sn} = normalized sleeve friction; q_t = corrected tip bearing w.r.t. area ratio and pore pressure; $R_f = f_s/q_t$ = friction ratio (%); p_{20} = SBPMT pressure at 20% strain (net pressure); β = SBPMT soil identification coefficient (%); G_{p0}, G_{p2}, G_{p5} = SBPMT shear moduli at 0% (initial), 2%, 5% strain; CBR = California bearing ratio; k = modulus of subgrade reaction; q_a = allowable bearing capacity; SF = safety factor; and X_1 = factor that depends on soil and foundation type.

CONCLUSIONS

The new chart presented here incorporates parameters from three different in situ tests. The original chart has been used in pavement design to provide preliminary estimation of a range of bearing values corresponding to a given soil classification. The new additions to the chart increase its versatility. The chart presents a comparison of soil classification predictions using parameters from three different in situ tests. It can be used to make preliminary estimates of the bearing values of subgrade soil, and of the classification of subgrade soil with given in situ parameters. It can also be used to derive approximate correlations between different in situ parameters, to verify test results, or to identify areas where a more extensive and detailed data base is needed. The chart is based on various existing correlations and assumptions. In the future, new findings and enlarged data bases may warrant updating

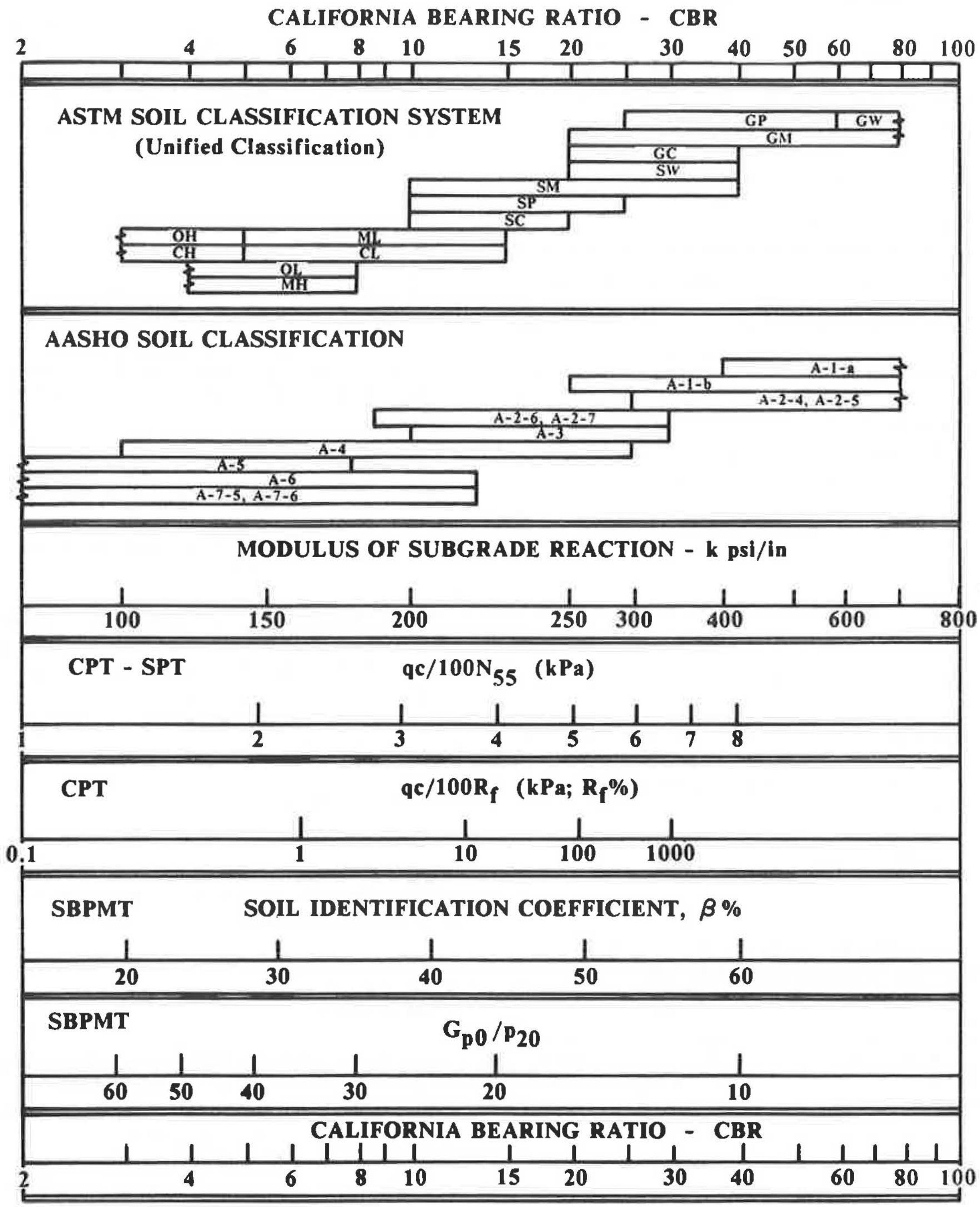

FIGURE 5 New chart for approximate interrelationships between soil classification, bearing values, and some in situ parameters (q_c, cone tip bearing; N_{55}, SPT blow count/ft at a standard energy ratio of 55; R_f, friction ratio (%); G_{p0}, shear modulus at 0% strain; p_{20}, pressure at 20% strain; CBR, California Bearing Ratio).

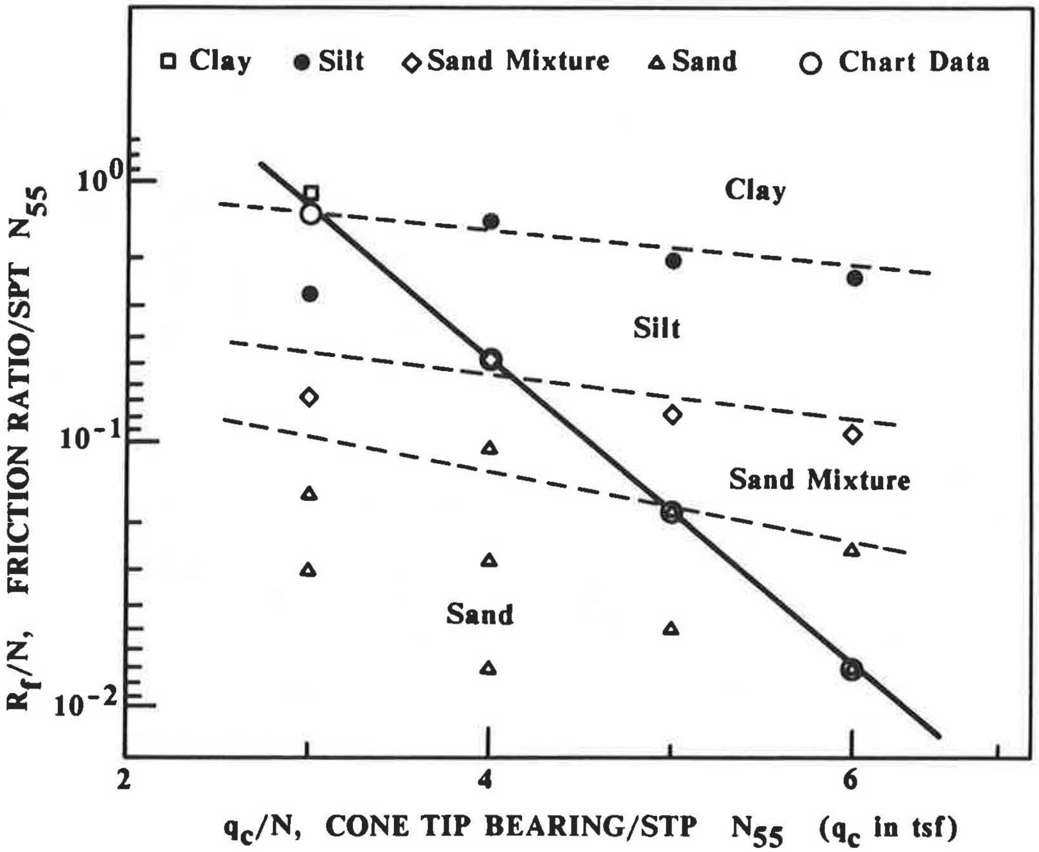

FIGURE 6 Comparison of the variation of R_f/N versus q_c/N from Olsen and Farr correlation (*3*) and the new chart with respect to soil classification.

TABLE 2 CORRELATIONS BETWEEN SBPMT AND PMT MODULI (*20*)

	G_{p0}/G_{p2}	G_{p2}/G_{p5}	G_{p2}/G_M	G_{p5}/G_M	G_{p0}/G_M
Clays	2.09	1.72	5.42	3.03	11.3
Sands	1.19	1.29	3.47	2.53	4.1

or modification of this chart. It should also be noted that field verification of the chart's predictions may be essential for reliable use of the chart.

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