DMT DIGEST #9
May, 1987

9A. Some interrelationships with p_o in clays

9A.1 p_o matches p_L: Because the insertion of the DMT blade creates an approximate plane strain cavity from initial thickness zero to the thickness of the blade, one might expect that the p_o pressure against the blade after this expansion would relate to the p_L limit pressure obtained from a PMT. The DMT should also produce a limit pressure, but for a nearly plane strain condition. Considering this alone, p_L should exceed p_o. However, because of the practical limits for the expansion in a PMT, engineers normally take p_L at a point two times the initial volume, vs. the infinite expansion ratio from zero volume that occurs with the DMT. Considering this alone would have $p_L < p_o$. The longer duration of the PMT also provides more time for pore pressure dissipation vs. the DMT A-reading taken within 30 seconds after blade insertion. This factor would decrease p_L vs. p_o. The net p_o/p_L ratio thus remains uncertain because of these and possibly other considerations, and probably varies somewhat with the type of clay tested.

Figure 9A.1 presents the first data the editor has seen which demonstrate a close correspondence between p_1 and p_L. For the old, stiff clays tested by the authors (Powell and Uglow, 1986), they obtained an approximate average p_1/p_L = 1.2. A separate review of their data by the editor showed that the three sites they investigated had average p_o/p_1 ratios of 0.68, 0.68 and 0.65 for an overall average = 0.67. This would give an approximate average p_o/p_L = 0.67 x 1.2 = 0.80 for these stiff clays. These data demonstrate the expected close relationship between p_o (or p_1) and p_L. Lutenegger reports in a personal communication that he has obtained similar data.

Engineers have had both theoretical and empirical relationships between s_u and p_L from the PMT for a long time. Thus, the above connection between p_o and p_L provides theoretical and empirical support for the existence of a correlation between p_o (and therefore K_D) and the undrained shear strength s_u. As 9C. herein shows, the DMT comparisons of s_u with the field vane test results are often very good.

9A.2 p_o mostly pore pressure in soft clays: Ever since the DMT pore pressure research data by Campanella and Robertson (see DIGEST item 5A.) DMT researchers have suspected that p_o in soft clays consists almost entirely of pore water pressure. Figure 9A.2.1, by Paul Mayne provides indirect evidence via the piezocone because it is known that almost all of q_c in soft clays results from pore pressure. Figure 9A.2.1 shows a close relationship between

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u_{max} from the CPTU and p_o from the DMT, and thus strongly supports the idea that most of p_o from the DMT also results from pore water pressure. Mayne is careful to note that in general one should not expect a 1 on 1 correspondence between pore pressures around the piezocone vs. against the DMT membrane because of the difference betweeen their axisymmetric and plane strain geometries. Again, Lutenegger reports similar data.

Boghrat (1987) recently published DMT pore pressure data demonstrating that most of p_o is effective stress in other than soft clay. Fig. 9.2.2 shows these data.

9A.3 p_o time-dissipation curves: Just as many research engineers attempt to interpret the pore pressure dissipation curves from CPTU testing for soil c_h (and c_v) and permeability, some (R. Gupta, A. Lutenegger, S. Marchetti et. al., P. Robertson et. al., and J. Schmertmann) are now attempting the same with the time dissipation of p_o and/or the C-reading. One can easily obtain such dissipation curves by taking a succession of A-readings or C-readings with time after blade penetration. Marchetti et. al. (1986) presented a number of A-reading dissipation curves, but for a different purpose. The dissipation of p_o involves the dissipation of total stress while that from the piezocone gives only the pore pressure part of the total stress. According to Robertson et. al. (1987) the dissipation of C-readings in soft clays approximates the dissipation of excess pore pressure. It is not clear at present which dissipation, A or C (total or pore pressure), is most advantageous for theoretical interpretation. As noted above, in soft clays almost all of p_o is pore pressure, so the initial total and pore pressures may not differ significantly. Preliminary results indicate we can be optimistic that this additional use of the DMT will provide c_v and k data useful for practice.

9A.4 Preconsolidation stress relates to pore pressure, and therefore p_o and K_D: Figure 9A.4.1 (Mayne, 1987) appears to show that σ'_{vmax} equals approximately $(p_o-u_o)/2$. Combining this with the observation that the total p_o approximately equals the excess hydrostatic pore pressure Δu in soft clays, then $K_D = \Delta u/\sigma_{vo}'$, giving equation 9.1 (Mayne, 1987). He obtained eqn. (9.2) using CPTU data and noted how closely it matches with the Marchetti 1980 empirical equation for OCR, given in eqn. (9.3).

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$$OCR \simeq 0.5\ K_D \quad \ldots\ldots\ldots\ldots \quad (9.1)$$

$$OCR = [0.46 \frac{\Delta u}{\sigma'_{vo}}]^{1.42} \quad \ldots\ldots\ldots\ldots \quad (9.2)$$

$$OCR = (0.5\ K_D)^{1.56} \quad \ldots\ldots\ldots\ldots \quad (9.3)$$

Mayne (1987) also plotted his data in the log OCR vs. log K_D form used by Marchetti, and got good agreement with the Marchetti correlation, as shown in Fig. 9A.4.2. His paper shows further that the form of eqns. 9.2 and 9.3 also results from cavity expansion theory used with critical state theory. It thus appears that this work by Mayne provides at least a partial theoretical understanding and basis for the Marchetti empirical equation.

9B. E_D vs. N-value Correlations

Paul Mayne has also shown (Law Engineering Testing Co. Memo dated 31 Mar 86) that E_D and SPT N-values correlate approximately linearly, as shown in Figure 9B.1. Any such correlation depends on soil type and is probably site specific. However, the fact that such a correlation may exist opens up the possibility of using N-values as a basis for extrapolating for DMT modulus values from similar soils at the same site. When doing this one should keep in mind the generally high coefficient of variation in N-value data, especially when performed by more than one drillrig-operator combination and without energy measurement corrections (ASTM D4633-86). We do not recommend using N-values to determine modulus values without site specific and perhaps also rig-specific correlation to direct modulus data, such as from the DMT.

9C. Updated DMT Correlations

The ASTM Suggested Method for the DMT (see 9E.) includes a TABLE 2 compilation of possible correlation errors based on the 1980 Marchetti correlations for clays and the Schmertmann 1982-83 correlations for sand. GPE, Inc. has continued to accumulate such correlation error information and Table 9C.1 herein presents our latest summary. We have been trying to accumulate enough information so that we can begin to subdivide to provide more detailed information about how well the present correlations appear to predict soil properties under different conditions. The following presents our first attempt at subdividing clays and gives some of our current general thoughts. "Sites" usually means individual sites, and an individual comparison usually denotes the mean at a DMT sounding for a distinct layer in

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that sounding, as mostly reported by authors of published papers but sometimes from nonpublished data accumulated by GPE.

9C.1 <u>OCR</u>: Based on 4 sites in sand and silts, the use of the DIGEST 1B. correlation method appears to overpredict OCR by 16%. In clay and organic soils the overall mean overprediction = 24% for 32 sites. However, the available data indicates a greater overprediction in old, overconsolidated and cemented clays, where the comparisons also show a very high degree of scatter. In very sensitive, almost "quick", clays there is a very strong tendency to overpredict OCR. A single site involving a dessicated, weathered clay crust also showed a poor, but conservative comparison. Three organic soil sites showed a good, slightly conservative comparison in generally normally or lightly overconsolidated soils. Removing the old, very sensitive and crust clay sites from the comparisons leaves 20 sites with a mean comparison error of about 12%. The OCR correlation methods presently used tend to overpredict OCR, especially in old clays and very sensitive clays and these may require local correlations. The current methods appear to overpredict by about 10-15% in all the remaining inorganic soils. The effect of such a 15% reduction has also been superposed on the correlations shown by Mayne in <u>Fig. 9.4.2</u> and any improvement is not obvious.

9C.2 <u>K_o</u>: <u>Table 9C.1</u> shows that there appears to be a strong tendency to underpredict K_o in old clays and clay crusts. The correlations when used in sands and all other clays overpredict K_o over the mean range of 11.4 to 15.6%. This magnitude of overprediction seems reasonable in view of the 9C.1 overprediction in OCR. Old clays and crust clays again need to be treated separately, perhaps by local correlation.

9C.3 <u>Settlement and M</u>: The 20 available settlement measurement comparisons show a mean error overprediction of settlement (underprediction of M) of less than 10%. This seems excellent and perhaps even superior to most alternate methods of making such settlement predictions. The range suggests that one can expect the blind use of the method (without adjustment for local experience) to predict ultimate settlements within a factor of approximately 0.67 to 2.0, with a standard deviation of 25% from the actual value.

Note that although the Italian chamber test data suggest the DMT will underpredict M and therefore overpredict settlement in OC sands, <u>Table 9C.1</u> shows no evidence that this occurs in real sands insitu.

The prediction of M, used inversely in a settlement analysis, shows about the same mean accuracy as using settlement directly, but with one important

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exception and also with considerably more scatter. The exception is the clay crust where the DMT may greatly overpredict M. The larger scatter in M predictions vs. actual settlement comparisons (std. dev. of 50 vs. 25%) may result partly from the scatter inherent in the other lab and/or field tests used for the comparisons.

9C.4 Undrained shear strength, s_u: Table 9C.1 shows that old clays and clay crusts give overall mean site overpredictions of s_u in the range of 25-35%. These clays apparently require a revised correlation, perhaps based on local experience. Excluding these clays gives a mean error of only +4% in all clays and 2% when the DMT s_u exceeds 0.5b., with a standard deviation of about 25%, vs. mostly high quality field vane tests (Norwegian and Swedish equipment) for the reference values of s_u. It appears that the present correlation adequately predicts s_u if we consider old clays and clay crusts separately.

9C.5 ϕ and unit weight, γ: Although the sites for these comparisons number only 5 and 6, resp., the mean values agree almost perfectly with the reference test measurements, with very little scatter. These correlations appear satisfactory at present.

9C.6 Old clays: It appears from the above that old clays (Miocene-Eocene), which typically behave as if they were overconsolidated, and which also have significant aging/cementation effects, behave differently than anticipated by the 1980 Marchetti correlations. Marchetti also warned about this. Using the 1980 correlations produces an overprediction of OCR and s_u, and perhaps surprisingly an underprediction of K_o. The settlement (or M) predictions seem less affected based on presently available comparisons.

9C.7 Very (near-quick) sensitive clays/silts: Although with skimpy data, it appears that the DMT can greatly overpredict M vs. lab oedometer values. However, these may be very low relative to insitu conditions and the DMT may actually overpredict settlements. The same problem applies to the OCR values. At the same time, very high sensitivity may not greatly affect the DMT s_u values vs. the field vane. Until further research provides more definitive data, one needs to be cautious in such soils and check the applicability of the DMT results and perhaps establish local correlations.

9C.8 Weathered clay crust: It seems clear that the special conditions with respect to soil structure existing within such crusts make them very

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TABLE 9C.1

GPE DMT VS. MEASURED COMPARISON SUMMARY, TO MAY 87

Property	Soil Class.	Soil type	No. "sites"	" error" = DMT-meas. / meas. (%) mean	std. dev.	extremes	Notes
OCR	sd. & si.	all	4	+16.3	23.2	-10 to +45	DIGEST 1B. method
	cl & org.	all	32	+24.4	52.0	-74 to +182	
		a. Old,OC, cem.	6	+32.7	92.2	-74 to +182	
		b. V. sensitive	5	+82.8	28.9	+50 to +128	nearly "quick"
		c. crust	1	-60			dessic., weathered
		d. organic	3	- 4.3	9.4	-15 to +3	
		all but a.,c.	20	+11.6	23.0	-39 to +80	REDUCE 15%?
K_o	sd. & si	all	5	+11.4	19.3	-14 to 31	DIGEST 1B. method
	cl & org.	all	16	+ 0.6	33.4	-69 to 35	
		a. Old,OC. cem.	4	-30.5	45.3	-69 to +35	
		c. crust	1	-40			
		all but a.,c.	11	+15.6	15.9	-15 to +30	REDUCE 10%?
$\left(\frac{1}{\text{settlement}}\right)$	sd. & si.	all	10	- 9.2	22.4	-55 to +20	JHS ´86 method
($\approx$M)	cl & org.	all	10	- 0.9	28.0	-40 to +42	vs. meas.
	org.	all	5	- 6.8	20.4	-30 to +20	settlement
M	sd. & si.	all	3	- 7.0	3.6	-10 to 0	vs. other lab
	cl & org.	c. crust	4	+302	330	-70 to +592	and/or field tests
		all but c.	27	+1.9	56.9	-79 to +140	- error conservative
s_u	cl & org.	all	54	+ 8.0	34.6	-50 to +160	I_D < 0.6
		= 0-0.2 bar	4	- 2.0	16.4	-22 to +15	mostly vs. field vane
		= 0.2-0.5 b	31	+ 3.8	27.8	-50 to +80	
		= over 0.5 b	17	+18.5	47.9	-29 to +160	
		a. Old, OC, cem.	6	+25.2	40.6	-20 to +79	
		c. crust	3	+34.0	111.1	-50 to +160	
		all but a.,c.	45	+ 4.0	24.3	-29 to +80	
		& over 0.5 b	10	+ 1.5	23.0	-24 to +38	
ϕ	sd. & si.	all	5	-1.0	6.8	- 7 to +10	I_D > 1.2, DIGEST 1B.
γ	clay & si.	all	6	+0.2	9.4	-11 to +10	

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suspicious with respect to using the 1980 correlations for soil property predictions. Many such crusts have slickensides and/or variable cementation and may have greatly different behavior en masse and also in the horizontal (DMT) direction vs. the vertical (OCR and settlement) direction. Some crusts may also behave as crushable soils and DIGEST item 1D. (Apr 83) warned about using the DMT correlations in crushable soils. Local correlations appear desireable at present until more research experience is available concerning a variety of such clay crusts. Professor Gunther Bauer, Carleton Univ., Ottawa, has performed some research regarding the use of insitu tests in crusts and may have a paper in the ISOPT-1 Proc..

9C.9 Organic soils: The various site comparison data that went into making up Table 9C.1 show that organic soils (OH,OL) and even some peats gave good DMT predictions of their compressibility and strength behavior. However, it remains possible that very fibrous peats with very high water contents and very low effective stresses may not produce good field behavior predictions using the DMT. In any event, the DMT testing of very weak organic soils near the surface requires an adequately sensitive gage (to measure the small A-B pressure difference) and may also require a sharpened blade (to cut fibers).

9C.10 Conclusions: It appears on the whole that the current data reduction procedures provide good accuracy, within the requirements of ordinary engineering practice. With the following exceptions we recommend their continued use as is:

a) The user should beware of current OCR, K_o, s_u and M correlations in weathered clay crusts, though locally developed correlations may still provide good results.

b) The DMT correlations seem to unacceptably overpredict OCR and s_u and underpredict K_o in aged and/or cemented clays. Again, local correlations may provide good results.

c) It appears that current procedures overpredict OCR and M in very sensitive clays. Again, local correlations may provide good results.

d) In general, the DMT methods in current use apparently overpredict OCR an average about 15% and K_o by about 10% in all "normal" soils (excluding the above). The magnitude of this adjustment is relatively small but may result in an improvement in the current correlations. Based on our preliminary indications, the engineer may wish to conservatively apply these adjustments in especially sensitive situations.

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As a service to our users, GPE, Inc. will continue compiling the available data, with special emphasis on developing correlations in problem soils such as those mentioned above. As we learn more, it should be possible to further increase the accuracy of the current correlations. Users are encouraged to submit their experiences and indicate any case histories which are not generally available.

9D. ISOPT-1

The ISSMFE Technical Committee on Penetration Testing, the sponsors of ESOPT-1 and -2, is now planning the first International Symposium on Penetration Testing ISOPT-1. ISOPT-1 will be held on Walt Disney World property during 20-24 March 1988. You should have received Bulletins 1 and 2 by now. If not, let us know. The DMT should be well discussed. One of the 8 invited lectures will be by Professor A. Lutenegger, with the tentative title "Current Status of the Marchetti Dilatometer Test". Professor Jamiolkowski has also offered to lead a specialty session (one of 18 planned) on the DMT. GPE will have a display booth on the DMT in the exhibitor's area. In addition, the authors of many of the over 100 papers expected for the ISOPT-1 Proceedings will probably have manned poster displays that will involve the DMT.

9E. ASTM Standard

As mentioned in DIGEST #8, the June, 1986 issue of the ASTM Geotechnical Testing Journal had an article presenting in detail the "Suggested Method for Performing the Flat Dilatometer Test". At its January, 1987 meeting in Tampa, ASTM Committee 18.02 decided to immediately follow up this publication with a regular committee to develop a published Standard Method for the DMT. Professor A. Lutenegger chairs this new committee D18.02.10. The likely changes to convert the "Suggested" to the "Standard" include:

1. Take out all soil property correlation formulae, but leave in I_D, K_D and E_D.
2. Make C-reading routine, and possibly include a pore pressure index U_D based on the C-reading. (more on this in D-10)

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If you have ideas about the new Standard, Professor Lutenegger will be pleased to have your input (Clarkson University, Dept. of Civil Engineering, Potsdam, NY 13676, 315-268-6519).

9F. References Cited:

1. Boghrat, A. (1987), "Dilatometer Testing in Highly Overconsolidated Soils", ASCE Journal of Geotechnical Engineering, Technical Note, Vol. 113, No. 5, May, p. 516.

2. Marchetti, S., G. Totani, R.G. Campanella, P.K. Robertson, and B. Taddei, (1986), "The DMT- σ_{hc} Method for Piles Driven in Clays", Proceedings of the Insitu ´86 Specialty Conference, ASCE, Blacksburg, VA, pp. 765-779.

3. Mayne, Paul W., (1987), "Determining Preconsolidation Stress and Penetration Pore Pressures from DMT Contact Pressures", scheduled for publication in the ASTM Geotechnical Testing Journal, Sep. issue.

4. Powell, J.J.M., and I.M. Uglow, (1986), "Dilatometer Testing in Stiff Overconsolidated Clays", Proceedings 39th Canadian Geotechnical Conf., Ottawa, p. 317.

5. Robertson, P.K., R.G. Campanella, T. Lunne, Trond, (1987), "Excess Pore Pressures and the DMT", draft paper for possible publication in Proceedings of ISOPT-1.

9G. Updated Index to DIGESTS

Our last Table 4J-1 index in June 84 included through DIGEST 4. The enclosed Table 9G-1 indexes DIGESTS 5 through 9 and follows a copy of Table 4J-1.

John H. Schmertmann
Editor

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TABLE 9G.1 - INDEX OF DIGESTS 5-9

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TABLE 4J-1 - INDEX OF FIRST 4 DIGESTS

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effects that cause the breakdown. Further sites need to be investigated.

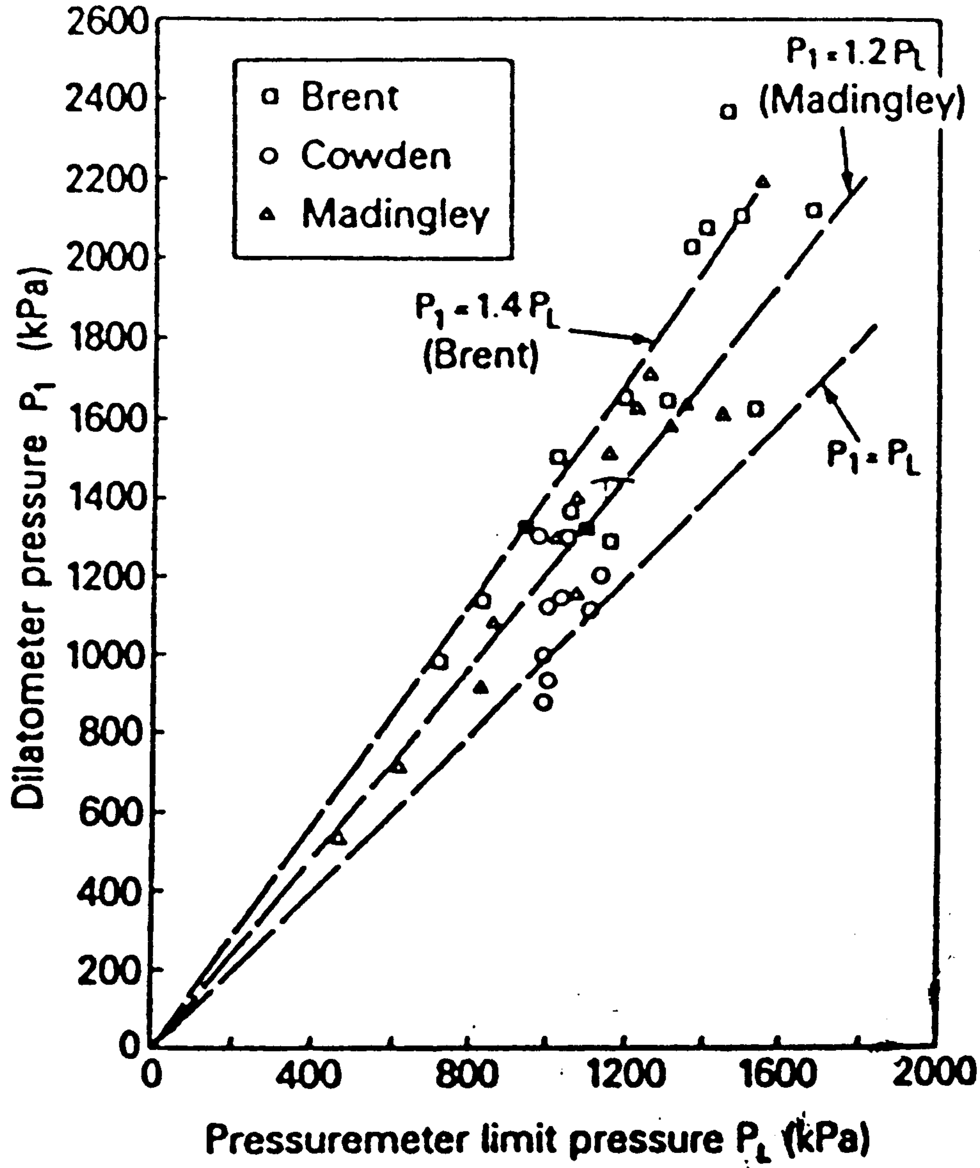

Figure 15 **Dilatometer pressure P_1 against Pressuremeter limit pressure P_L**

FIGURE 9A.1

(from Powell & Uglow, 1986)

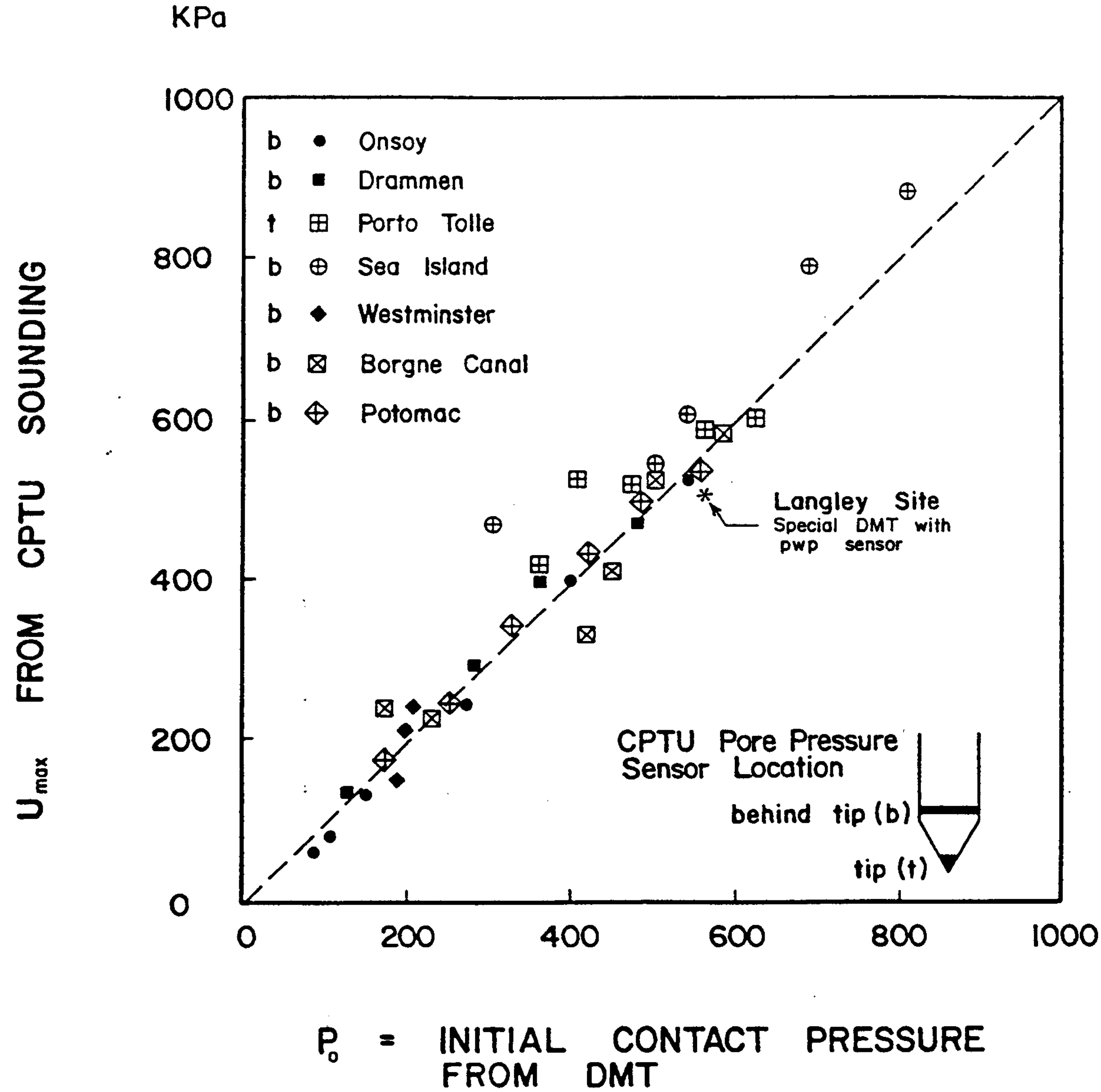

FIGURE 9A.2.1

from: Mayne (1987)

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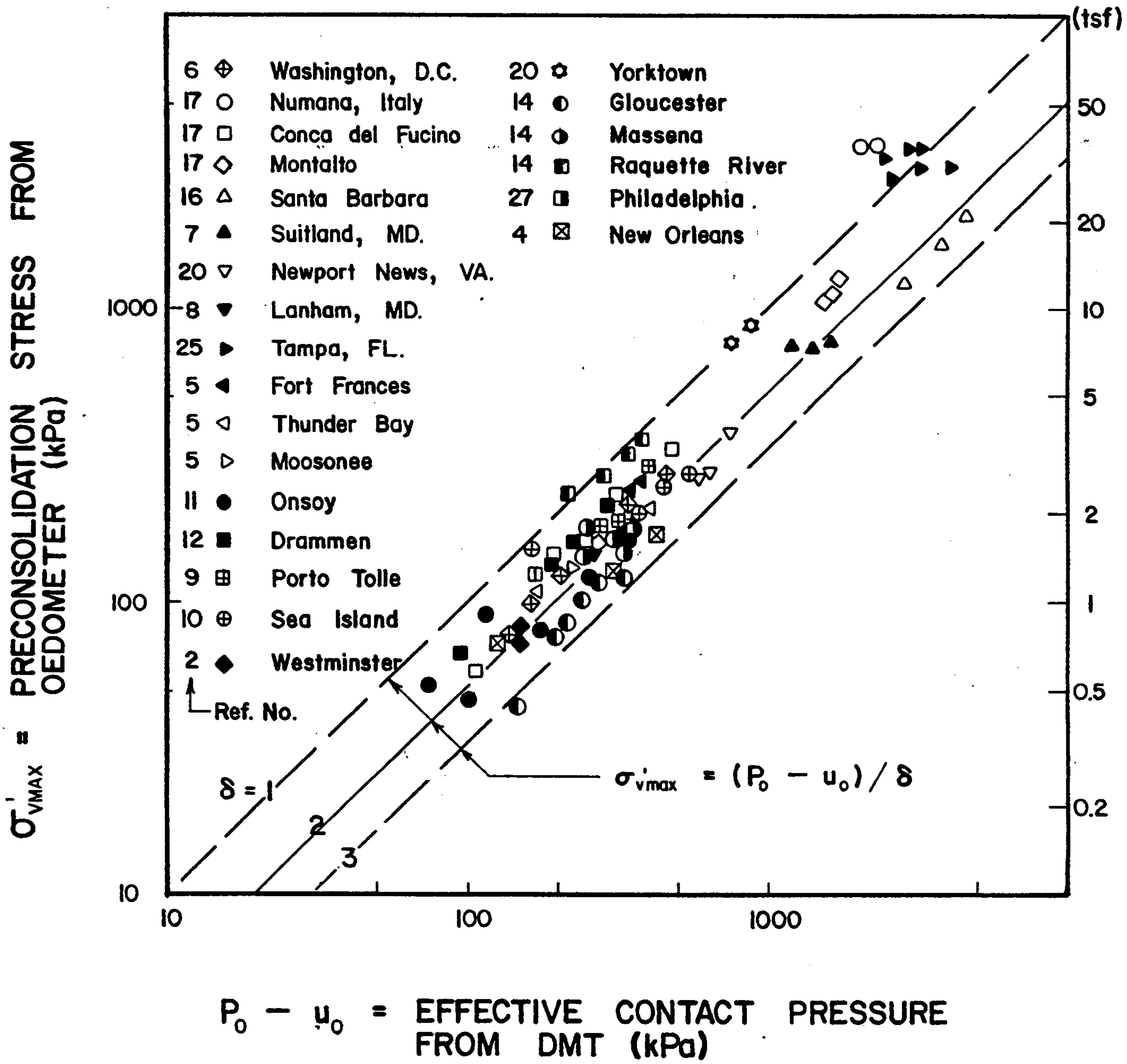

FIGURE 9A.4.1

(from: Mayne, 1987)

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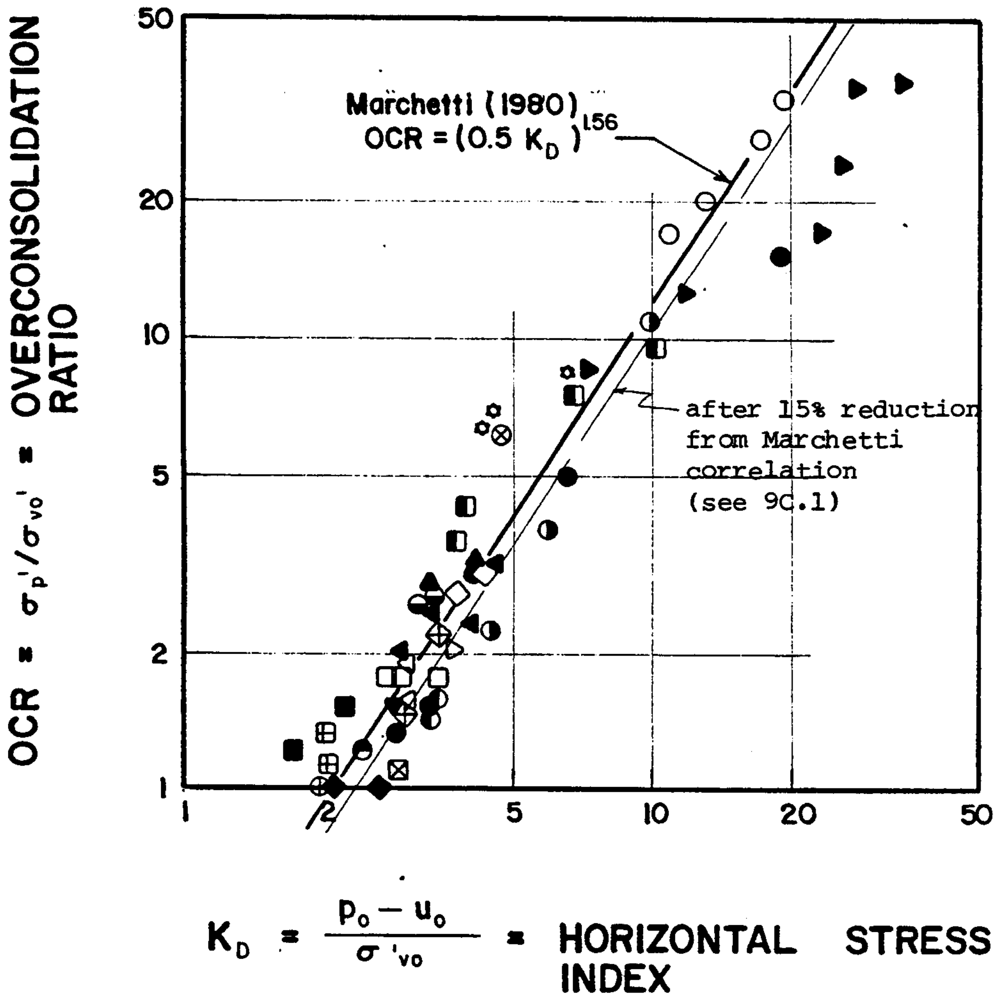

FIGURE 9A.4.2

(from Mayne, 1987)

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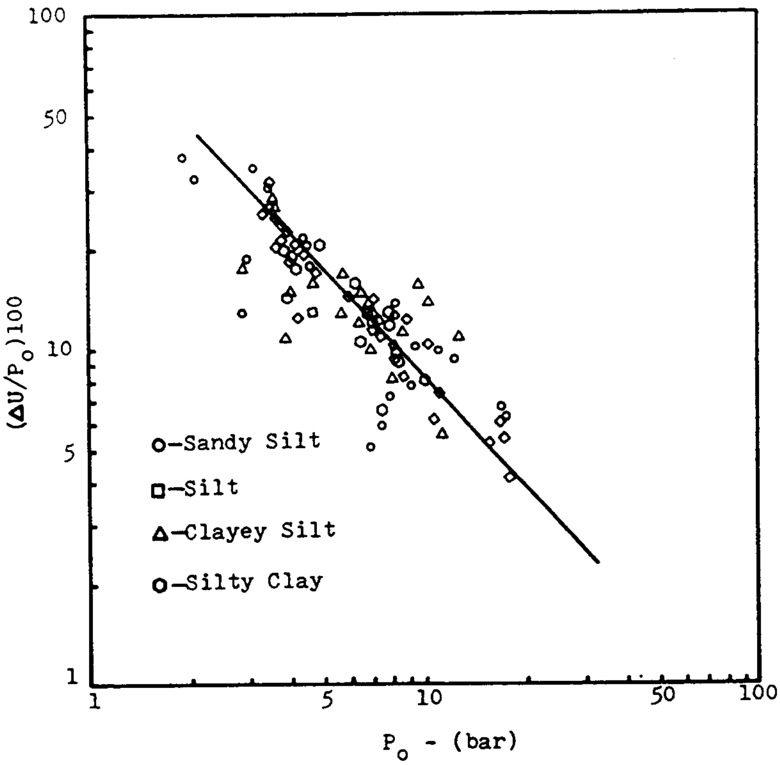

FIG. 2.—Relation between P_0 and $\Delta u/P_0$ for Four Different Soil Types

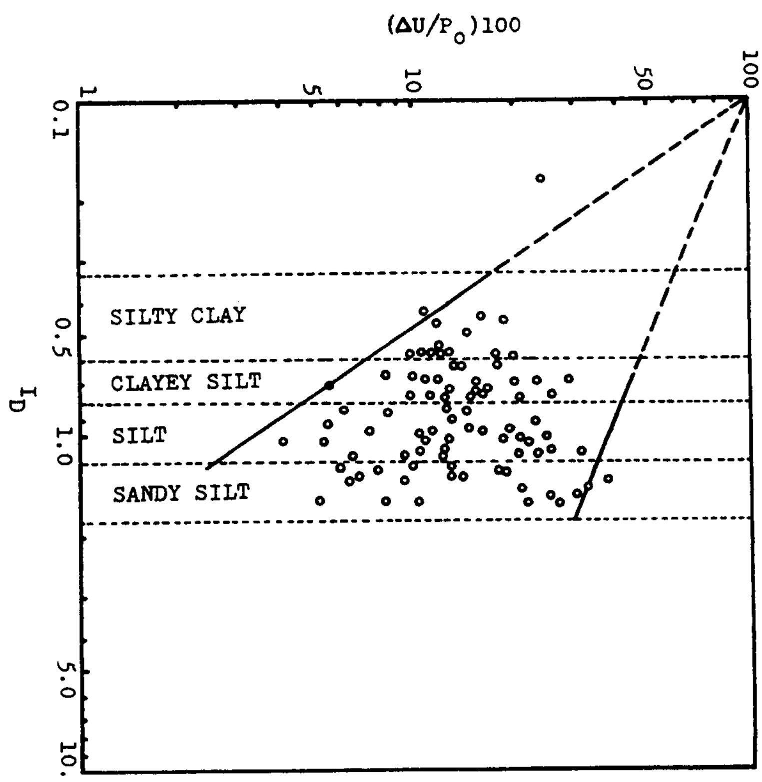

FIG. 3.—Relation between I_D and $\Delta u/P_0$

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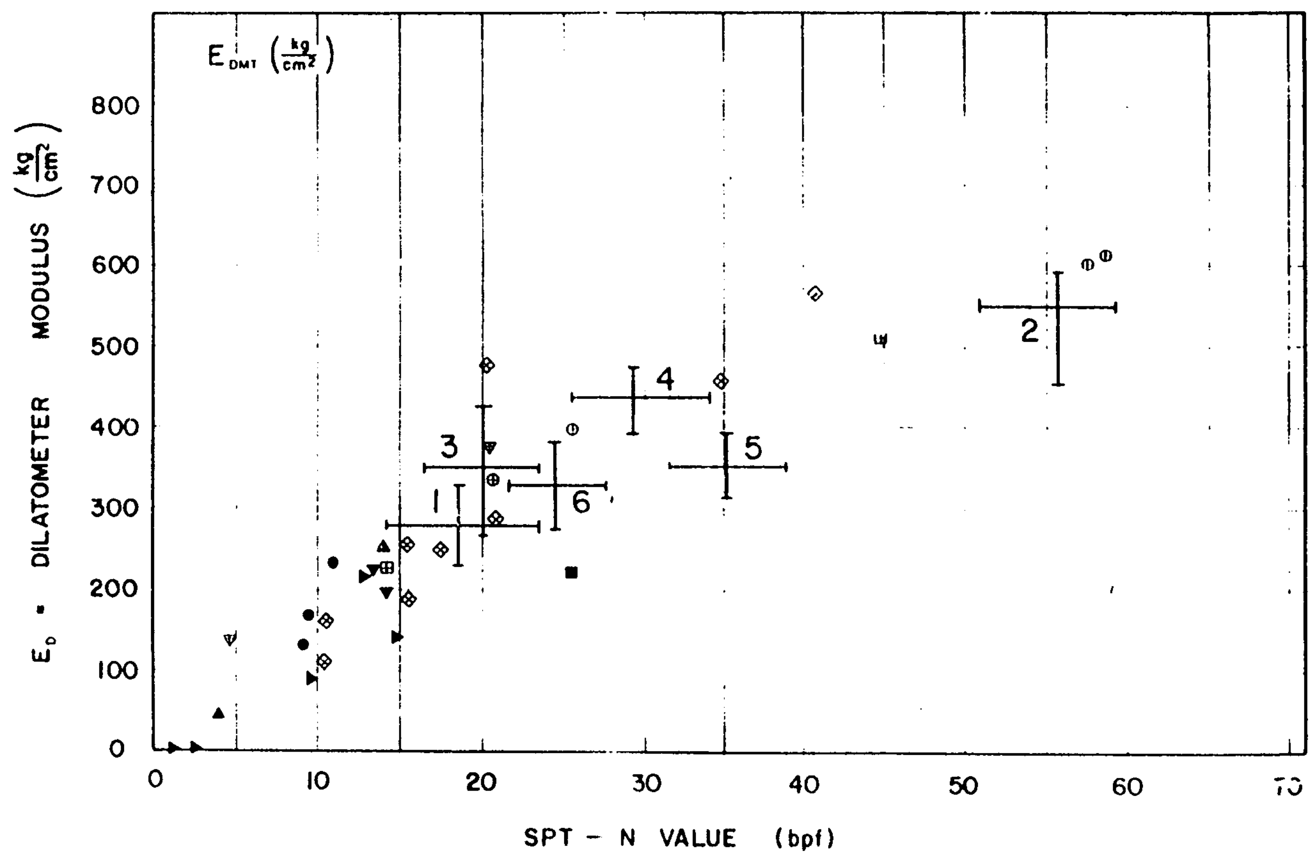
FIGURE 9A.2.2
From Boghrat (1987)



BACKCALCULATED MODULUS

1. NADA — Mat
2. Honeywell — Footings
3. Embassy Suites — Mat
4. American Center — Mat
5. Fairfax Hospital — Drilled Pier
6. Fairfax Hospital — Bored Pile

FIGURE 9B.1

From:
Law Engr. memo
P. Mayne, 1986

RESIDUAL SOILS

BACKCALC. MODULI

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