DILATOMETER DIGEST NO. 5
Feb, 1985

5A. U-Reading to Measure Water Pressure

We are excited about what appears to be a simple way to significantly expand the scope of data obtained from the DMT.

As pointed out by Campanella et. al. [1, see 5H. for references], the corrected closure pressure when the membrane returns to the A liftoff position, after deflation from the B-reading, may closely equal the pore water pressure. It appears the soil itself may not rebound fast and/or far enough to exert a significant effective pressure against the membrane immediately after deflation.

Herein we shall refer to the pressure when the signal returns after the deflation as the U-reading. When corrected for the ΔA calibration and gage zero this reading becomes the p_w pressure. In the case of testing in sands p_w approx. = the insitu water pressure u_o before inserting the blade because insertion and testing usually generate negligible excess pore pressures. The possibility of some effective soil pressure and positive excess pore pressure still on the membrane after deflation makes it likely that p_w will usually provide an upper limit value for the desired u_o in sands. However, this upper limit may nearly equal the correct value of p_w -- as suggested by the data in subsequent Fig. 5A-2. In clays, p_w = approx. the pore pressure generated as a

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result of the blade insertion because only small dissipation takes place during the test. Figures in 5A-1, taken from [1], showed this p_w behavior in sand and soft clay for the first time by measurement using the special University of British Columbia research dilatometer.

GPE has tried the method at one site, with the favorable results shown in Figure 5A-2. Part (a) of this figure shows the p_w results from a DMT sounding made at about low tide immediately adjacent to a salt water marsh and p_w fits nicely between the range of hydrostatic pressures from the tidal range. Part (b) shows p_w data from 2 soundings, 400 ft. apart, that appear to show a possible surprise transition from hydrostatic as determined from a shallow boring and the lesser sea level hydrostatic in the underlying limestone (a deep salt water channel c. 1 mi from the DMT probably intersects the limestone).

Our study of Fig. 5A-2 data, and other p_w data from this site, suggests a tentative lower limit of $I_D = 1.2$ (boundary between silty SAND and sandy SILT) for the use of p_w as approximately equalling the insitu water pressure u_o. However, we do not know if I_D by itself provides an adequate guideline for success of the method. For example, high K_o values might indicate that the sand will likely follow the deflation and provide some effective soil pressure. As we and others gain experience we will provide additional guidelines.

The annotated photo in Figure 5A-2(c) shows the additional equipment used for the p_w measurements in parts (a) and (b). To obtain an accurate U-reading requires some control of the venting deflation process as the membrane reapproaches zero inflation and we have inserted an additional flow control valve to control the final stage of the venting. Our experiments indicate that a deflation time of about 15 to 30 seconds between the B- and U-readings gave acceptable results at this site. Because insitu water pressures usually have low values, one needs to use a suitably sensitive gage to obtain a suitably accurate U-reading. The 16 bar gage, and the 1.5 bar calibration gage are suitable for this purpose. Of course, adding a sensitive gage requires putting a valve in the system to protect it against overload during the deflation and then opening the valve manually (or automatically) when the pressure drops within the range of the gage.

Campanella et. al. [1] report that similar type closure pore pressure behavior has been observed with pressuremeter testing. Jamiolkowski, et. al. [13, Fig. 51] present an example. Some PAF self-boring pressuremeter testing in New Orleans clay, as presented by J. Canou and M. Tumay [2] gave the computed results shown in Figure 5A-3. These data show some scatter, but the average of the PAF deflation closure pressures gave nearly the hydrostatic u_o, even though this pressuremeter testing took place in a soft, New Orleans clay.

Based on the aforementioned experiences, GPE makes the recommendation that users of the DMT try this technique for themselves for the simple, approximate measurement of u_o in sands with $I_D \geq 1.2$. The total U-reading procedure added about 1 minute to a DMT. It should prove particularly useful as a check on the usually assumed hydrostatic pore pressure condition (perched water tables?, artesian layers?, transitions as in Fig. 5A-2(b)?) by

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performing the U-readings in sand layers. U-readings might also sometimesprove useful to help define the position of a simple water table, for example when the use of drilling mud makes borehole data uncertain or borings are not available. Note: Should insitu water pressure conditions differ significantly from the hydrostatic assumed in most of the DMT data reduction programs, then you should substitute your best estimate for the field-correct water pressures into the calculations to give more accurate values for the effective stresses used in the data reduction.

5B. DMT for Liquefaction Potential

Robertson and Campanella [6] have suggested a tentative correlation between K_D and liquefaction potential, as presented in Figure 5B-1. Liquefaction potential decreases with increasing relative density, increasing cementation, and also increasing K_o values, all of which also increase K_D -- hence the correlation.

Other investigators have in the past, or are presently, looking into possibilities of using the DMT for liquefaction evaluation. Professors G. Leonards and J. Chameau at Purdue University currently have an NSF project to study various insitu testing devices, including the DMT, for the evaluation of liquefaction potential at field sites in California. Marchetti has also written a paper discussing his then (1982) current views about the possibilities of using K_D to estimate liquefaction potential [5].

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5C. DMT for Control of Dynamic Compaction

The enclosed Figure 5C-1 shows a recent advertisement by the GKN-Baker Company describing a very large ground improvement project near Jacksonville, FL at which hey used deep dynamic compaction (DDC) to improve the upper approx. 30 ft. Although the engineers controlled the work using the CPT, extensive DMT work provided the reference M modulus values against which they correlated the CPT for control test purposes. Another dynamic compaction engineer-contractor Geosystems Inc., also recently recently purchased DMT equipment for control testing purposes.

The DMT appears to be a technically good, and economically practical tool for checking the results of ground improvement work such as dynamic compaction in sands. As an example of this, Table 5C-1 presents some greatly condensed results from a test area at the project illustrated in Figure 5C-1. The larger test area was divided into test sections, and in the first three of these Baker obtained DMT and electric CPT data within the upper 20 to 27 ft before and after DDC compaction (dropping a 33 ton weight from 105 ft).

A number of observations seem possible that apply to the above site and the DDC effect used: First, the modulus and cone bearing improvement at pts. midway between the DDC prints results from both increases in lateral stress and densification. Secondly, the post DDC DMT K_o reaches an average limit of about 1.3 irrespective of the initial K_o condition. However, the average DMT K_o-condition can increase substantially as shown by the 0.66 to 1.17 increase

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at Test Section 2. Thirdly, we have another example showing how the 1-D modulus M from the DMT increased much more than the cone bearing capacity increased, by a factor of about 2.3 at Test Section Nos. 2 and 3. The previous DIGEST items 3C and 4D noted the much greater instrument-displacement soil disturbance effects of the CPT vs. the DMT. This probably explains why the DMT senses a much greater proportion of the modulus increase after dynamic compaction than that reflected by CPT q_{cv} values.

5D. Lower Bound Subgrade Modulus

DIGEST item 4G, with Figure 4G-1, suggested a way of using DMT data for evaluating the horizontal subgrade modulus, k_h. Some readers have sent in their comments to the effect that k_h by this method appears to produce too-low values. Most likely the problem results from the use of a secant modulus, as illustrated in Figure 4G-1. The actual p-y curve may have a greater curvature than illustrated in this figure, and probably reaches a limit pressure in most cohesive soils. For such cases the suggested procedure would produce a k_h value considerably less than an initial tangent or a secant based on the expansion of a thinner wedge. The method suggested for k_h in 4G thus can be thought of as usually producing a lower bound value.

Assuming the above reasoning correct, then the method suggested in 4G. would become less conservative as the soil volume and shear strain required for failure are increased. In this case the DMT blade wedges the soil apart without exceeding the limit pressure and more accurately reflects the initial

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tangent modulus.

Another reason for possible too-low k_h values involves the Terzaghi formula suggested in 4G. to reduce k_h as size increases. Reductions by this formula may or may not be excessive, but we do not know of data to suggest a better formula.

5E. Tentative Use of $E_D = E_{25}$ in Sands

Evidence has accumulated from 2 sources to suggest that the dilatometer modulus, E_D, may be used directly to estimate the equivalent secant Young's modulus in NC sands at about the 25% strength degree of mobilization. Campanella, et. al. [1] suggested this approximate relationship. M. Jamiolkowski, et. al. [3, Table XIII] has also reported similar findings from recent calibration chamber tests by ENEL. These tests also show, in a very preliminary way, that the E_{25}/E_D ratio increases with OCR. The results from two tests with simple OCR = 2.7 and 5.4 suggest that the ratio equals approximately 0.7 OCR.

Engineers usually require some equivalent Young's modulus, E, for the calculation of deformations in sands and not the M currently determined from the data reduction of DMTs (even though settlement predictions may be made using M directly). Converting M to E involves another correlation step. Going directly from E_D to E in sands at least potentially improves the accuracy of determining E and GPE recommends its preliminary use for sands

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with low OCR.

E_{25} represents a typical degree of mobilization in static load problems. Lesser mobilization loadings (as in vibration transmission problems), or greater (as in near-failure conditions) will of course require appropriate modification of the E_D-to-E_{25} ratio.

5F. GEOSPEC Article, Ground Engineering Ad

In case you have not seen them, you might find the enclosed 2 p. article and 1 p. advertisement of interest.

5G. Marchetti Method for Friction Angle, K_o and OCR Calculation in Sands Not Recommended

Marchetti did not have a DMT correlation for friction angle in sands in his 1980 ASCE paper [4]. Subsequently, he did develop a preliminary, conservative method for estimating friction angle. However, this empirical method produces very conservative results and GPE considers it generally unsatisfactory. We recommend its use be completely discontinued. We use only the method developed in [7], which is linked with K_o and OCR as discussed in previous DIGESTs 1B. and 3D., and which appears to produce generally good results in uncemented cohesionless soils.

The [7] method does require a measurement or estimate of the thrust

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required to advance the blade. Unfortunately, making such a measurement or estimate is not always possible or convenient. However, we believe you must make such a determination to permit the approximate separation of the sand-strengthening effects of increased density (and therefore friction angle) and increasing insitu effective stresses. In the absence of a measurement or estimate of the thrust force or the measurement or estimate of blade end bearing capacity, q_D (which approximately = q_c from the CPT), we presently recommend not attempting a friction angle, K_o and OCR prediction from the DMT when I_D exceeds 1.2. Marchetti had a very limited sand data base from which he proposed his preliminary method and he strongly cautioned about its preliminary nature. He also agrees to the superiority of the [7] method, as do Jamiolkowski et.al.[3, p. 57] indirectly by their favorable method [7] experience with K_o predictions and no mention of the preliminary Marchetti method.

5H. References

[1] Campanella, R.G., P.K. Robertson, D.G. Gillespie and J. Greig (1985) "Recent developments in In-Situ Testing of Soils", XI ICSMFE, San Francisco, 1985. (also in UBC SM Series #84, Sept 84).

[2] Canou, J. and M. Tumay (1984) "Calibration and Field Evaluation of the French self-boring pressuremeter (PAF 76)", Report No. GE-84/04, Civil Engineering Dept., Louisiana State University, Nov, 419 pp.

[3] Jamiolkowski, B.M., C.C. Ladd, J.T. Germaine and R.Lancelotta (1985) "New Developments in Field and Laboratory Testing of Soils", Theme Lecture, Session 2, XI ISCMFE; San Francisco, 1985.

[4] Marchetti, S. (1980) "In Situ Tests by Flat Dilatometer", Journal of the Geotechnical Engineering Division, ASCE, Vol. 106, No. GT, Proc Paper 15290, Mar. 1980, pp. 299-321.

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[5] Marchetti, S. (1982)
"Detection of liquefiable sand layers by means of quasi static penetration tests", Proceedings, 2nd European symposium on Penetration testing, Amsterdam, pp. 689, vol. 2, May, 1982.

[6] Robertson, P.K. and R.G. Campanella (1984)
"The Flat Plate Dilatometer Test for Liquefaction Assessment". Univ. of British Columbia, Dept. of Civil Engineering, Soil Mechanics Series #79.

[7] Schmertmann, J.H. (1982)
"A method for determining the friction angle in sands from the Marchetti dilatometer test (DMT)", Proceedings, 2nd European Symposium on Penetration Testing, Amsterdam, p. 853, Vol. 2, May 1982.

John H. Schmertmann
Editor

The DMT DIGEST editorial staff invites contributions from its readers detailing test experience and/or helpful observations, for possible inclusion in future issues. Please mail to:

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Gainesville, FL 32606

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Table 5C-1 - Ave. Results from before and after Dynamic Compaction in the Test Area, using 33 ton weight dropping 105′ (all tests in approx. center between DDC prints 24′ apart)

In Test Section*	No. drops	depth interval	from DMTs					from electric CPTS	
			No. Tests	K_o		M(b)		q_c (b)	
				before	after	before	after	before	after**
1	2	3-20′	26	1.30	1.34 (+3%)	1050	1680 (+60%)	83	n.a.
2	6	5-24′	30	0.66	1.17 (+77%)	680	2290 (+237%)	83	165 (+99%)
3	6	6-27′	32	0.98	1.19 (+21%)	1230	1590 (+54%)	121	150 (+24%)

* Tests 100 ft apart between Sections 1 and 2.
Tests an additional 160 ft apart between Sections 2 and 3.

** q_c values increased with time after the DDC, as did M values also.
The q_c values given are for the time of the DMTs.

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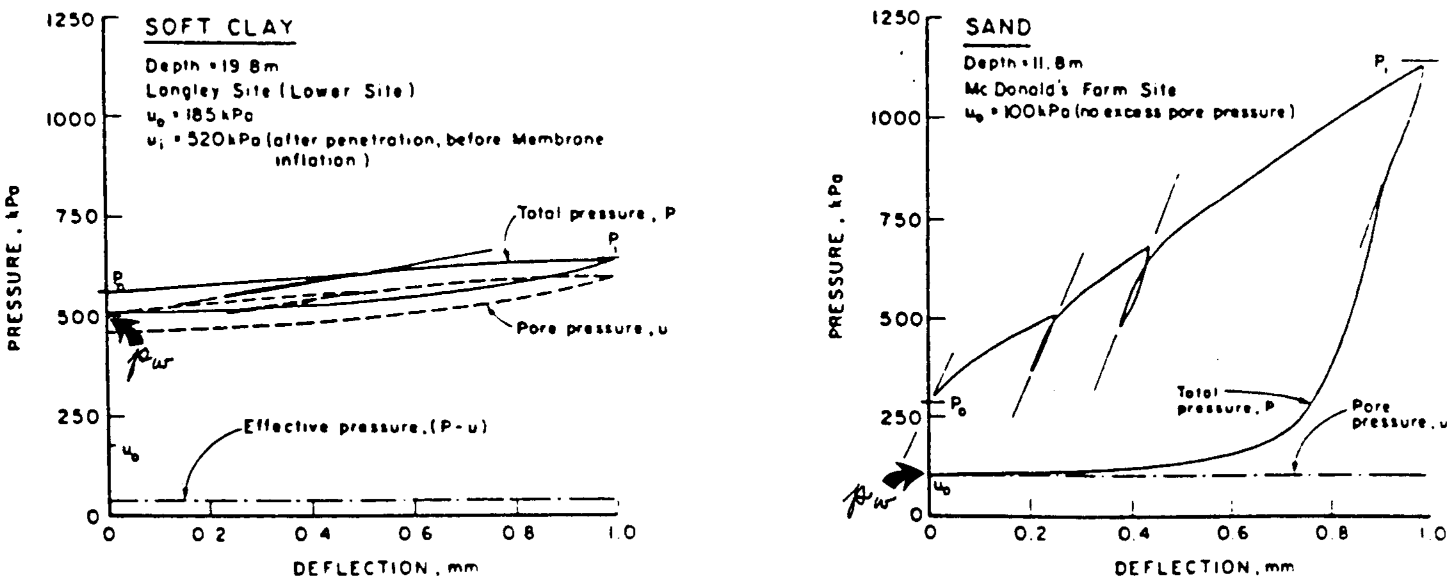

Fig. 4. Typical results from Research DMT in sand and soft clay deposits.

FIGURE 5A-1 - FIRST PUBLISHED EXAMPLE OF APPROXIMATION
$p_w = u_o$ IN SANDS AND = u IN CLAYS
from: [1] with p_w arrows added

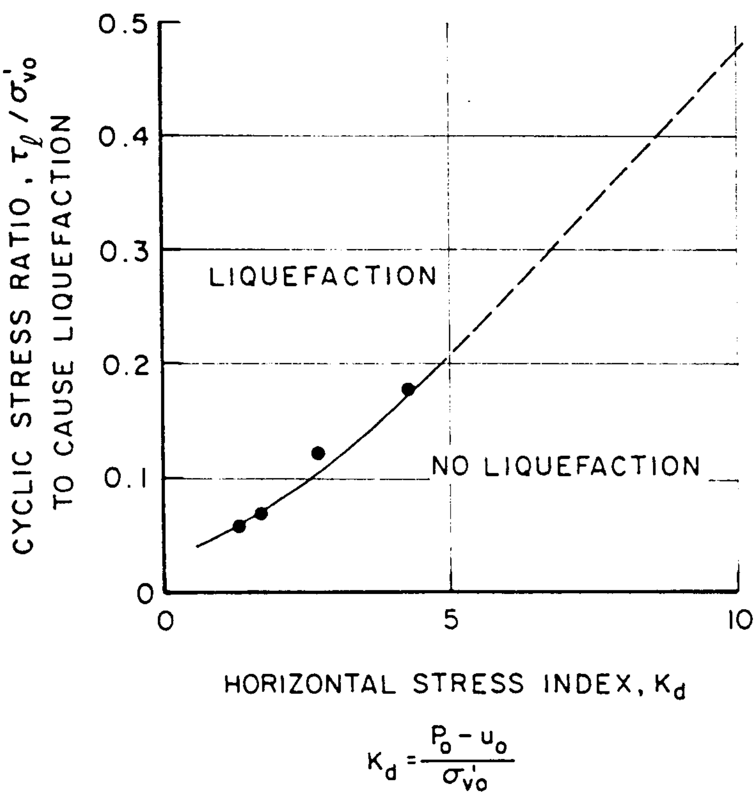

FIGURE 5B-1

from [5]

Figure 3. Proposed Correlation Between Liquefaction Resistance Under Level Ground Conditions and Dilatometer Horizontal Stress Index for Sands.

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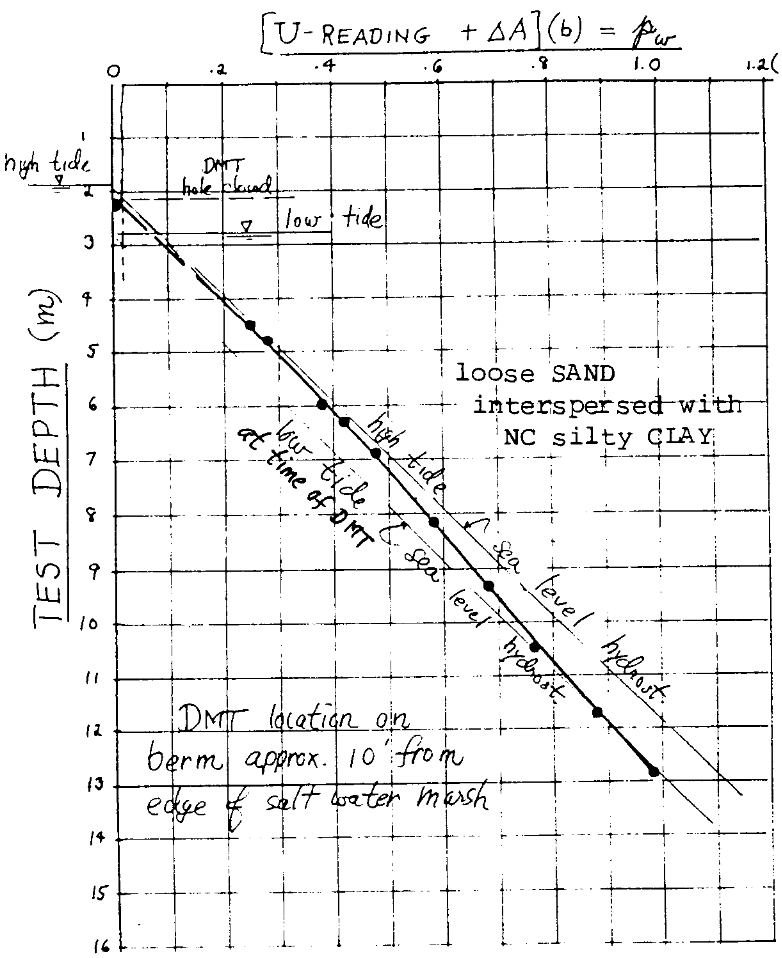
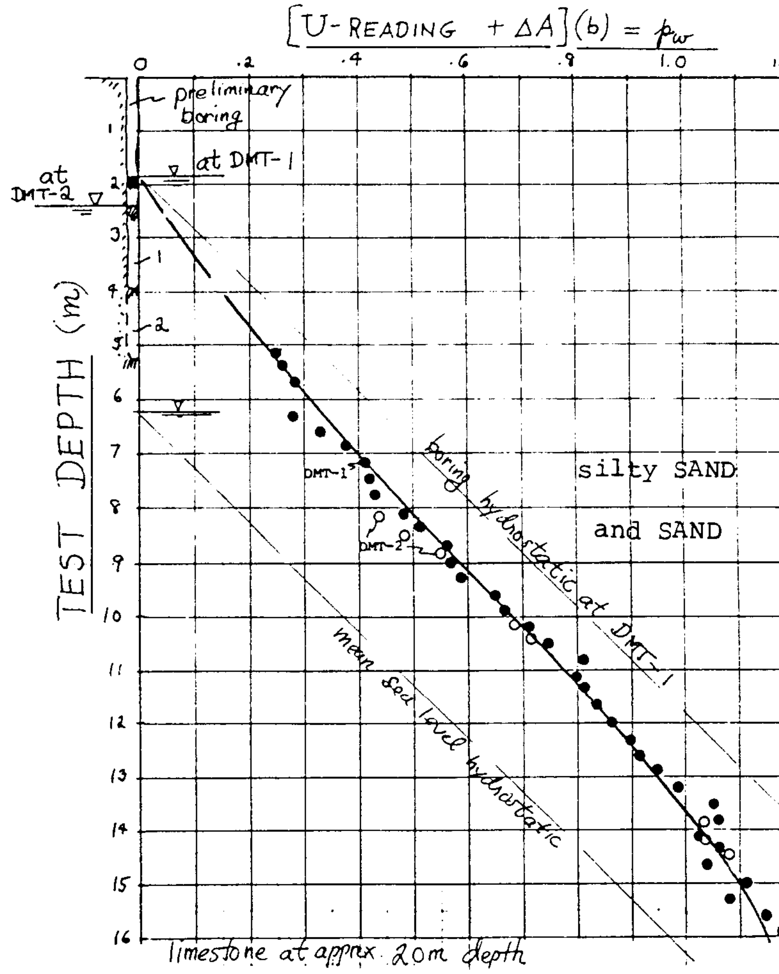
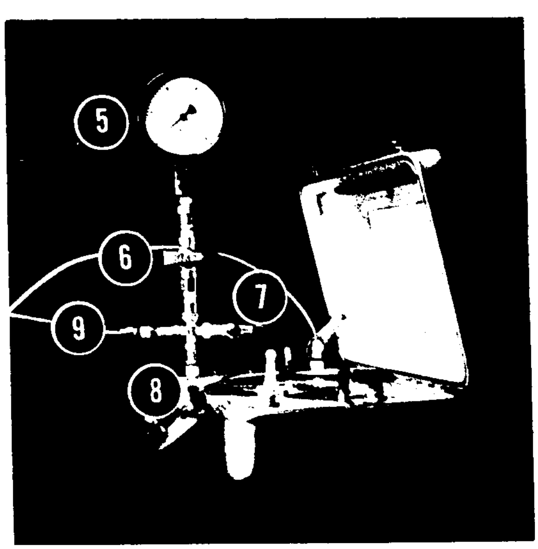


(a) Results of all U-readings from one DMT sounding taken adjacent to sea level. (min/ave/max I_D values at U-readings = 1.4/3.1/4.7)



(b) Results of all U-readings taken from two DMT soundings 400 ft apart and c. 1 mi. from a deep salt water channel. (min/ave/max I_D values at U-readings = 1.5/2.2/3.8)



(c) Additional equipment used for the U-readings

FIGURE 5A-2

RESULTS OF FIRST GPE ATTEMPT TO USE U-READINGS TO DETERMINE INSITU u_o WATER PRESSURES

5. Gage with 2.5b range.
6. Cutoff valve to protect gage.
7. Additional flow control valve.
8. The whole assembly quick-connects into the control box and is left in place during ordinary A- and B-readings.
9. Line from blade also quick-connects.

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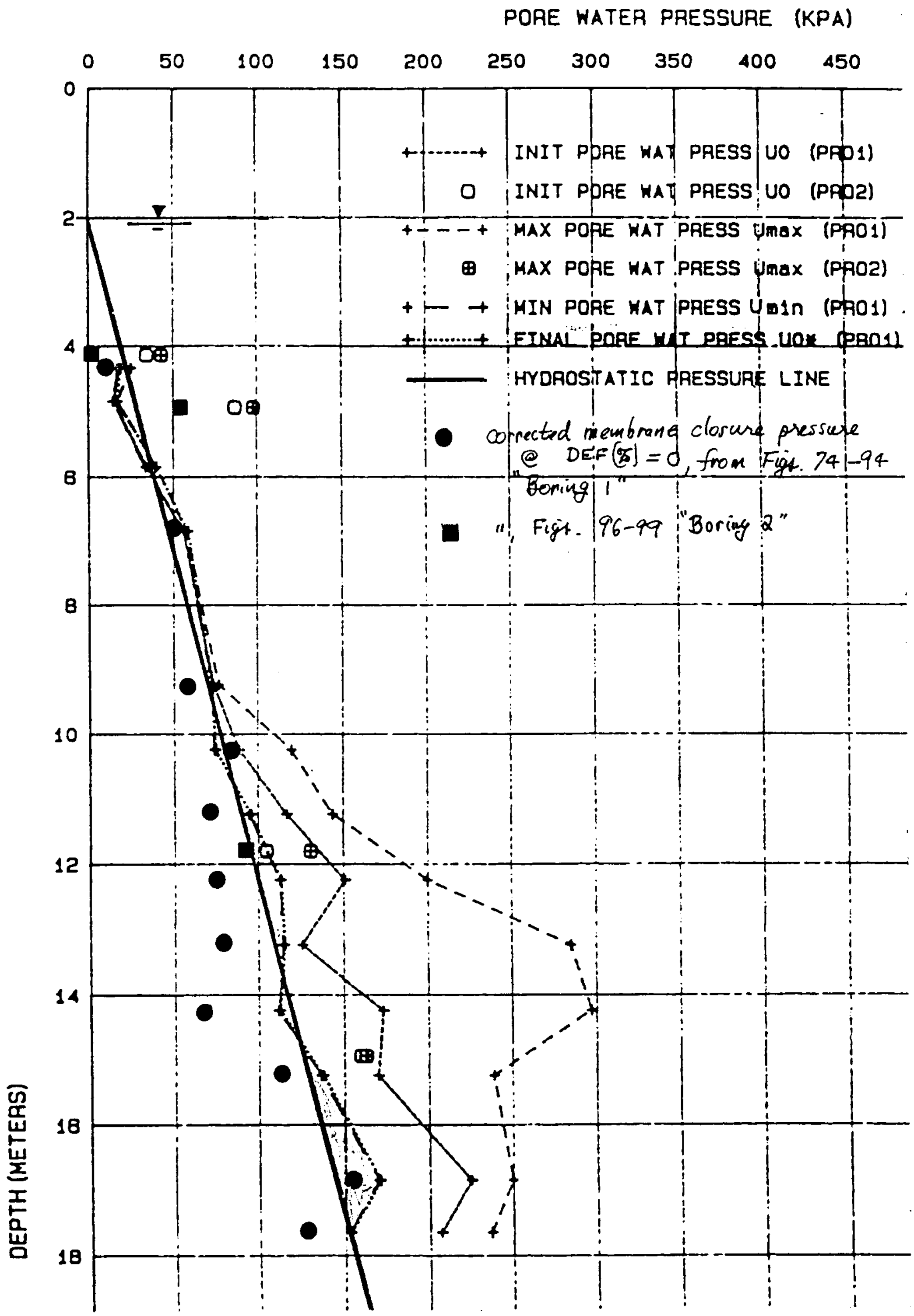

FIGURE 5A-3 - COMPARISON OF HYDROSTATIC WITH DEFLATION CLOSURE PRESSURE FROM TESTS USING PAF76 SELF BORING PRESSUREMETER, TESTING NEW ORLEANS CLAY AT A SITE ADJACENT TO A CANAL

(Fig. from Canou & Tumay ref. cited in text, with solid points calculated by GPE)

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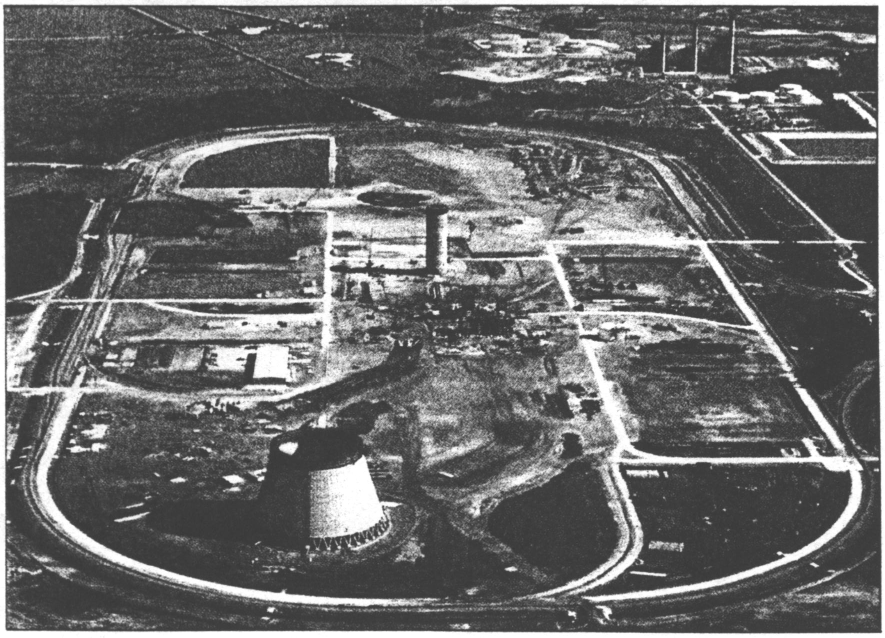
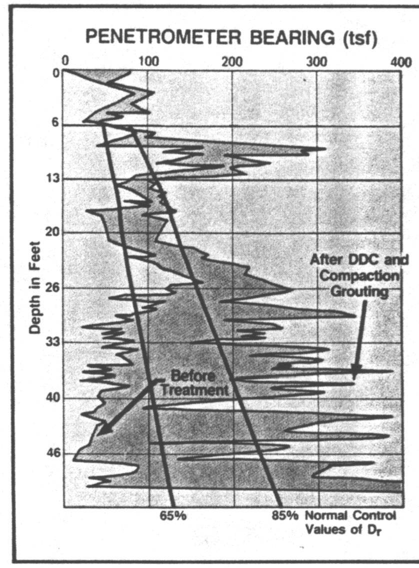




Penetrometer measurements demonstrated conclusively the improvement achieved through Ground Modification.

PROBLEM: Differential Settlement

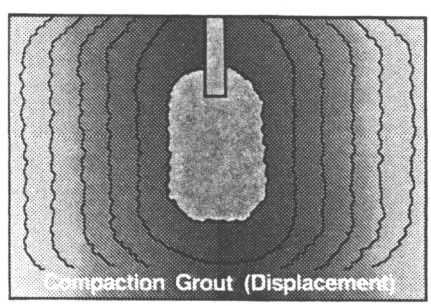
Two coal-fired generating stations are being built on this 1,600-acre site by the Jacksonville Electric Authority and Florida Power & Light. Borings showed the upper 40- to 50-ft layer consisted of loose to medium-dense sand over a 10-ft layer of soft, silty clay. Severe differential settlement was anticipated.

Dynamic Deep Compaction involved dropping heavy weights 100 ft from specially rigged cranes.

BEST SOLUTION: Ground Modification[sm]

When confronted with such conditions, many designers consider pile-supported foundations. But engineers at Ebasco Services, JEA, and FP&L determined that a combination of mat and spread-footing foundations placed on densified soils would prove significantly less expensive than a ten-million-dollar pile design. Densification alternatives were designed and evaluated. Specialty contractor GKN Hayward Baker worked with Ebasco to test and then perform a comprehensive Ground Modification[sm] program which cut costs by some six million dollars.

We used Dynamic Deep Compaction™ to increase the sand layer's 60% relative density to 85%. A 36-ton weight was dropped repeatedly from heights up to 100-ft at precisely determined primary and secondary drop points.



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THE NEW IN-SITU MARCHETTI DILATOMETER TEST

John H. Schmertmann

A skeptical "It's too good to be true!" expressed my first reaction when Italian Professor Silvano Marchetti told me in 1977 about his newly invented DMT. Two years later he persuaded us to try his novel test in our consulting practice. We quickly became converts and now use the DMT routinely. For example, the geotechnical investigation for the project featured on the cover of the Dec.-Feb., 1984 issue of this magazine included 1000 DMTs, with 750 from offshore barge soundings. Also, our geotechnical professional equipment company, GPE, Inc., now markets the equipment in North America.

The photo shows the basic DMT equipment. It consists of a stainless steel blade (1), 94 mm wide and 14 mm thick with a sharp edge (2) and a 60 mm stainless steel membrane (3) centered on and flush with one side of the blade. A single, combination gas and electrical line (4) extends from a surface control and gage box (5) through the rods and down to the blade. The operator uses a flow control valve (6) to increase the gas pressure and measure it at two points in the membrane expansion—the first at membrane "lift-off" and the second after a 1.0 m movement, both prompted by an audio signal. He or she then immediately vents the gas and pushes or drives the blade to the next test depth, usualy 0.15 to 0.30 m deeper, and repeats the 1 to 2 minute test cycle.

At each test depth the engineer obtains the effective horizontal stress in the form of K_0, the shear strength in the form of either s_u for clays or Ø for sands, the compressibility or modulus in the form of the $M = 1/m_v$, the OCR or preconsolidation stress, and the type of soil penetrated. The correlations involved use of a combination of empirical and theoretical equations. The hand held HP 41C does nicely for data reduction in the field and any of the desk top computers will suffice in the office. Note that the above parameters represent basic properties which the engineer can use in any rational method of analysis. Furthermore, he or she gets each parameter at closely spaced depth intervals, which allows vertical profiling and a good evaluation of stratigraphic effects.

We have used the DMT in a wide variety of soils, from the extremely weak and compressible (peats, clay, slime and sand mine tailings) to the very strong and incompressible (very hard clays, sand after dynamic compaction). The writer has accumulated a number of case comparisons which give an indication of the accuracy you might expect from the present correlation equations. The table presents a summary to date (June '84), without attempting any refinements for soil type, geology, etc. It shows that the DMT results have adequate accuracy for most ordinary work.

A dozen universities in North America have begun to use the DMT for both teaching and a great variety of research projects. About 10 consultants and contractors now use it in their practice. The writer expects that the DMT will enjoy a wide acceptance by geotechnical engineers who upon exposure usually seem quick to recognize its many advantages. Refer to Marchetti, "In-Situ Tests by Flat Dilatometer," ASCE Journal GED, March, 1980, pp. 299-321, for more information or you can write or call GPE, INC., 4509 NW 23rd Avenue, Suite 19, Gainesville, FL 32606 (904 378-2792).

DMT accuracy comparison 'Error' = $\left(\frac{\text{DMT-other}}{\text{other}}\right)$

	K_o	Ø	S_u	M	OCR
Average	+7%	+1%	+2%	-18%	+1%
standard deviation	22%	—	27%	33%	30%
Range: max.	+30%	+1%	+80%	+20%	+50%
min.	-40%	0%	-47%	-79%	-60%
No. comparisons	11	2	22	22	17
Range of Values in comparisons	0.3 to 1.6	33° to 37°	0.007 to 0.8 bar	2 to 500 bar	1 to 15

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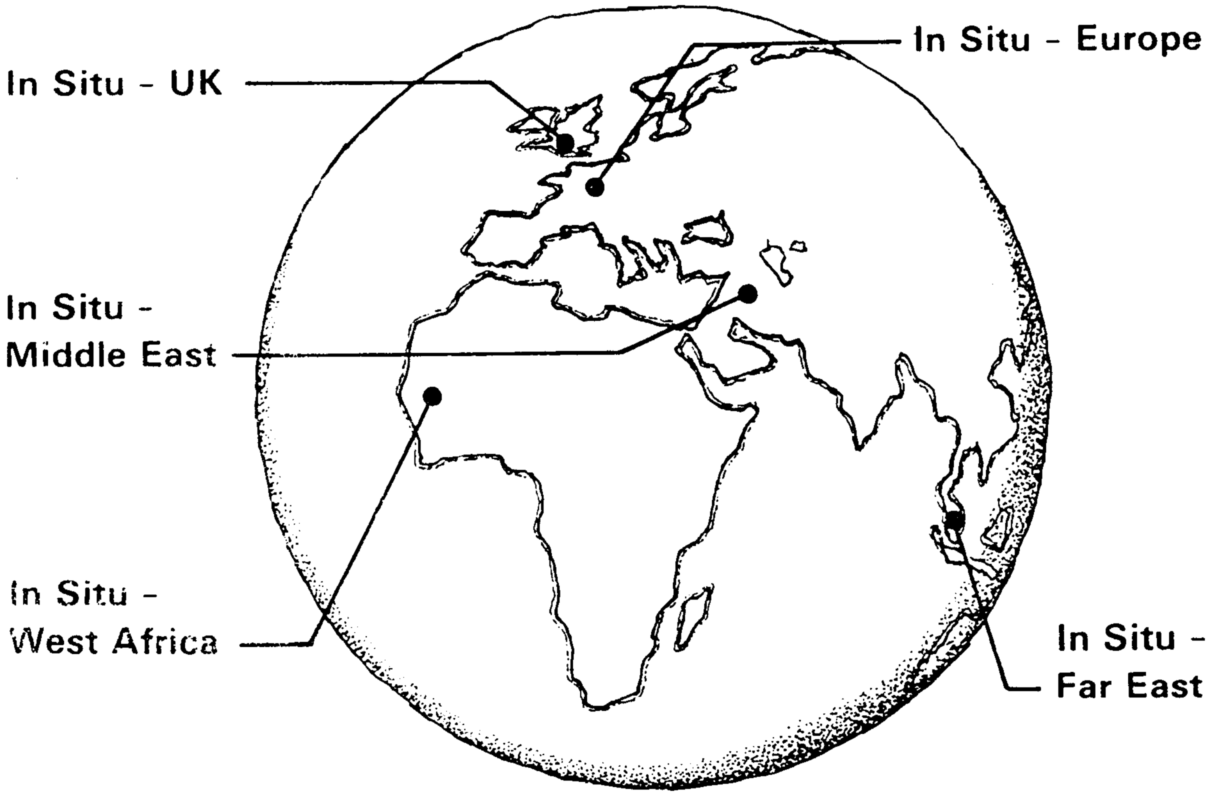

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