A PORTABLE DYNAMIC PENETROMETER FOR GEOTECHNICAL INVESTIGATIONS

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INTRODUCTION

Most of us are frustrated by our human inability to "see" into the ground. Without special instruments, we can only see, probe, or squeeze the very surface of the ground. Such looks, probes, and squeezes give little reliable information about its ability to support loads because its supporting properties depend upon the soils' strength, deep within the ground.

The authors have developed and tested a lightweight dynamic cone penetrometer which one person can carry to remote locations where he can readily test for strength properties to deep within the soil. A means of injecting fluid into the cone path annulus to reduce parasitic friction dynamic energy loss is described. A logging program which quickly reduces the penetrometer's blow count data to dynamic cone resistances, plots these resistances, and interprets them, is described and illustrated.
Calibration of this dynamic cone penetrometer has been accomplished by the authors' correlations of side-by-side dynamic cone resistances with Standard Penetration Test N values in various soil types. This paper proposes correlations between this penetrometer's dynamic cone resistances and SPT N values.

THE NEED FOR A PORTABLE SOIL EVALUATION INSTRUMENT

The normal commercial structure needs and generally receives a subsurface exploration including test borings with SPT N values and laboratory strength testing of soil samples. But it is often impractical to use test borings to:

a. preliminarily explore the subsurface in densely wooded, building covered, swampy, or steep terrain sites.

b. explore the subsurface for single-family residences.

c. evaluate earth fill compaction.

d. verify footing bearing capacities during construction.

REQUIREMENTS FOR A PORTABLE PENETROMETER

For such a penetrometer to be most useful, it must be usable by a single person; portable, in that it can be carried to test locations; small enough to travel in the trunk of a car; versatile enough to test any soil type; sensitive enough to differentiate between weak, medium, and strong soils; and simple to interpret.

DESIGN OF THIS DYNAMIC PENETROMETER

The authors followed these specifications to develop and test a light dynamic cone penetrometer with the characteristics of:

a. An unmotorized (hand-raised) hammer with a 35 lb weight and a 15 inch drop, to provide the energy for driving a 10 cm^2 projected area cone. This can be transported in a car trunk, carried by one person, and worked by one person to test all but the most consolidated soils. As testing progresses below the first meter, additional 1 meter long sounding rods are screwed onto the rod string.

b. A fluid injection system, pumps a cellulose/water mixture into the annulus between the 1.4" diameter cone path and the 1.1" diameter rods, minimizing parasitic friction on the rods. Consequently, undiminished hammer energy is transmitted to the cone, allowing confident use of the Dutch Formula to calculate cone resistance (q_d). The rods slip out of the "lost point" cones to be pulled from the slurry- filled hole by hand. Cellulose slurry biodegrades.

c. A simple spread-sheet computer program logs the hammer blows per 10 cm; calculates, plots, and tabulates dynamic cone resistances (q_d); and tabulates consistency adjectives.

Unfortunately, this penetrometer, like other dynamic cone penetrometers, does not ascertain the grain size of the tested soils. Consequently, although the data tells much about soils' relative densities, the data does not indicate whether the soils are clay, silt, or sand. Where determination of soil grain sizes is important, that information must be found by some method other than by dynamic cone testing.

REDUCTION AND LOGGING OF DYNAMIC PENETROMETER DATA

In this paper, dynamic cone resistance, q_d, is the cone resistance pressure in Kg/cm^2, calculated by the "Dutch Formula". In that formula,

$$q_d = \frac{M^2 \times H \times N_d}{A_p(M + M' + P_a)10}$$

where,

M= Mass of the hammer = 35# x 0.453 = 15.89 Kg
H= Height of Drop = 15" x 2.54 = 38.1 cm
N_d= Number of blows per 10 cm of drive
A_p=Projected area of the cone = 10 cm2
M'= Mass of the driven portion of the hammer = 2.49 Kg
P_a= Mass of the rod string = 3.26 Kg x the number of rods.

This means that the dynamic cone resistance, in Kg/cm^2, is:

4.44 x N_d for 1 sounding rod
3.86 x N_d for 2 sounding rods
3.42 x N_d for 3 sounding rods
3.06 x N_d for 4 sounding rods
2.77 x N_d for 5 sounding rods

$2.54 \times N_d$ for 6 sounding rods
$2.33 \times N_d$ for 7 sounding rods
$2.16 \times N_d$ for 8 sounding rods
$2.01 \times N_d$ for 9 sounding rods
$1.89 \times N_d$ for 10 sounding rods

The program for logging a dynamic cone penetration test is illustrated in figure 1. The hammer blows per 10 cm are entered. A spread sheet program tabulates these figures, and calculates, tabulates, and plots the dynamic cone resistances. The program also tabulates three columns of consistency adjectives: one for sand, one for silt, and one for clay.

PENETROMETER CALIBRATION BY CORRELATIONS WITH SPT N VALUES

Since many of us in North America are most comfortable evaluating soil strengths from Standard Penetration Test in-situ test results, we have correlated dynamic cone resistance of the dynamic penetrometer with SPT N values by using both test types in close proximity. In the reduction of the correlation test data, we compared the average of three 10 cm long dynamic cone resistances with the corresponding 12 inch SPT N value.

Soil samples are a byproduct of SPT testing, so we took the opportunity to either visually estimate or test for the mean soil particle size of each SPT test sample. These determinations of d_{50} in mm were used in our q_d/N versus d_{50} plot of Figure 2.

(Robertson, Campanella, and Wightman, 1983) in correlating static cone resistances, q_c with SPT N, found that q_c/N increased from approximately 1 for clays to approximately 8 for sands. We have not found a similar increase of q_d/N to be characteristic of dynamic cone resistances. Perhaps because the dynamic cone penetrometer and the Standard Penetration Test both employ a dynamic penetration force, their relationships are more linear than the relationship of static cone and dynamic SPT.

Figure 3 plots our currently available q_d versus N correlations. Each plotted point indicates whether it is a clay, silt, or sand soil type. By plotting q_d directly, rather than the ratio of q_d/N, one can see how at higher blow counts, the q_d/N values increase. We believe that this is caused by the relatively low energy of the dynamic penetrometer, compared to the higher energy of SPT.

CONCLUSIONS

We do believe that this dynamic cone penetrometer, as developed, is a valid instrument for estimating approximate strengths of nearly all soils to reasonable depths. it correlates well with N values of SPT borings. With q_d values up to 90 Kg/cm^2, q_d/N ratios are approximately 3.5.

Two technical reservations of this penetrometer should be understood. The first reservation is that this penetrometer tells nothing about whether a soil is clay, silt, or sand. The second reservation is that when the q_d values of the cone exceed approximately 90 Kg/cm^2, SPT N values exceed 25, but are indeterminate.

Most soil evaluation concerns focus on soils with SPT N values less than 15. This penetrometer provides a continuous stream of accurate soil strength data through the entire 0 to 25 range of SPT N values. Consequently, the penetrometer is both usable and most valuable in the soils that require the most concern.

TRIGGS TECHNOLOGIES, INC.
33977 CHARDON ROAD
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SHEET #:	1
FILE #:	1
STARTED:	4/27/90
COMPLETED:	4/27/90

****
WILDCAT DYNAMIC

CONE PENETROMETER LOG
****

CREW:	ACT	SURFACE ELEVATION:	
TEST #:	DEMO	HAMMER WEIGHT:	35 LBS.
PROJECT:	NONE	CONE AREA:	10 SQ. CM
LOCATION:	HAYES DRIVE	HAMMER DROP:	15"

DEPTH FT	DEPTH M	BLOWS PER 10 CM	RESISTANCE KG/CM^2	TESTED CONSISTENCY SAND	SILT	CLAY
	0.1	3.0	13.1	LOOSE	LOOSE	MEDIUM
	0.2	4.0	17.4	LOOSE	LOOSE	MEDIUM
1	0.3	55.0	239.8	COMPACT	DENSE	HARD
	0.4	14.0	61.0	FIRM	DENSE	VERY STIFF
	0.5	26.0	113.4	COMPACT	DENSE	HARD
2	0.6	19.0	82.8	FIRM	DENSE	HARD
	0.7	15.0	65.4	FIRM	DENSE	VERY STIFF
	0.8	13.0	56.7	FIRM	MEDIUM	VERY STIFF
3	0.9	10.0	43.6	FIRM	MEDIUM	VERY STIFF
	1.0	10.0	43.6	FIRM	MEDIUM	VERY STIFF
	1.1	9.0	33.7	FIRM	MEDIUM	STIFF
4	1.2	9.0	33.7	FIRM	MEDIUM	STIFF
	1.3	8.0	30.0	LOOSE	LOOSE	STIFF
	1.4	9.0	33.7	FIRM	MEDIUM	STIFF
5	1.5	7.0	26.2	LOOSE	LOOSE	STIFF
	1.6	7.0	26.2	LOOSE	LOOSE	STIFF
	1.7	7.0	26.2	LOOSE	LOOSE	STIFF
6	1.8	8.0	30.0	LOOSE	LOOSE	STIFF
	1.9	9.0	33.7	FIRM	MEDIUM	STIFF
	2.0	7.0	26.2	LOOSE	LOOSE	STIFF
7	2.1	6.0	19.7	LOOSE	LOOSE	STIFF
	2.2	6.0	19.7	LOOSE	LOOSE	STIFF
	2.3	10.0	32.9	FIRM	MEDIUM	STIFF
8	2.4	8.0	26.3	LOOSE	LOOSE	STIFF
	2.5	8.0	26.3	LOOSE	LOOSE	STIFF
	2.6	12.0	39.5	FIRM	MEDIUM	STIFF
9	2.7	9.0	29.6	LOOSE	LOOSE	STIFF
	2.8	10.0	32.9	FIRM	MEDIUM	STIFF
	2.9	7.0	22.8	LOOSE	LOOSE	STIFF

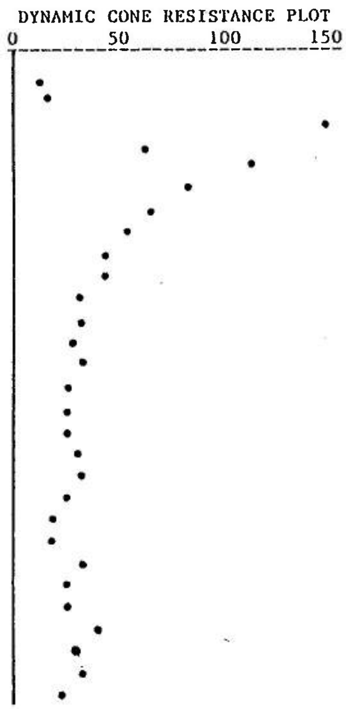
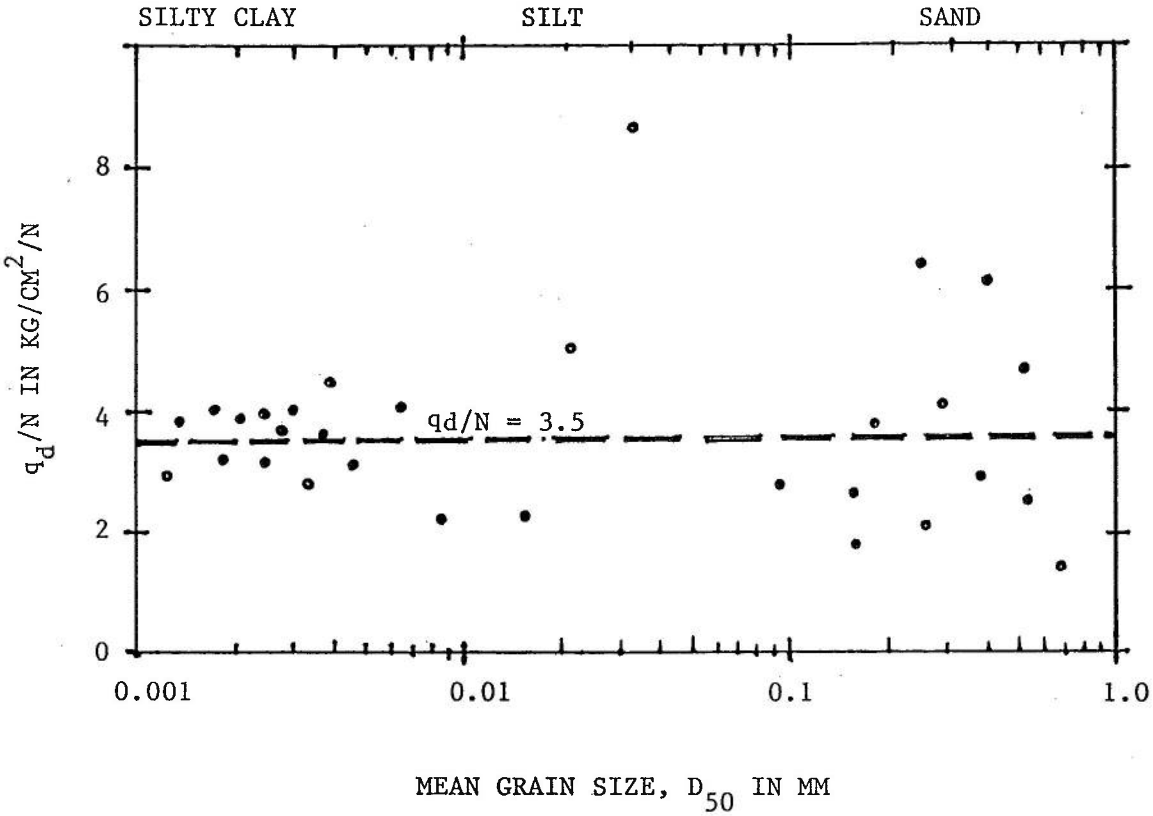


FIGURE 1



SILTY CLAY
SILT
SAND
q_d/N IN $KG/CM^2/N$
0
2
4
6
8
qd/N = 3.5
0.001
0.01
0.1
1.0
MEAN GRAIN SIZE, D_{50} IN MM

FIGURE 2

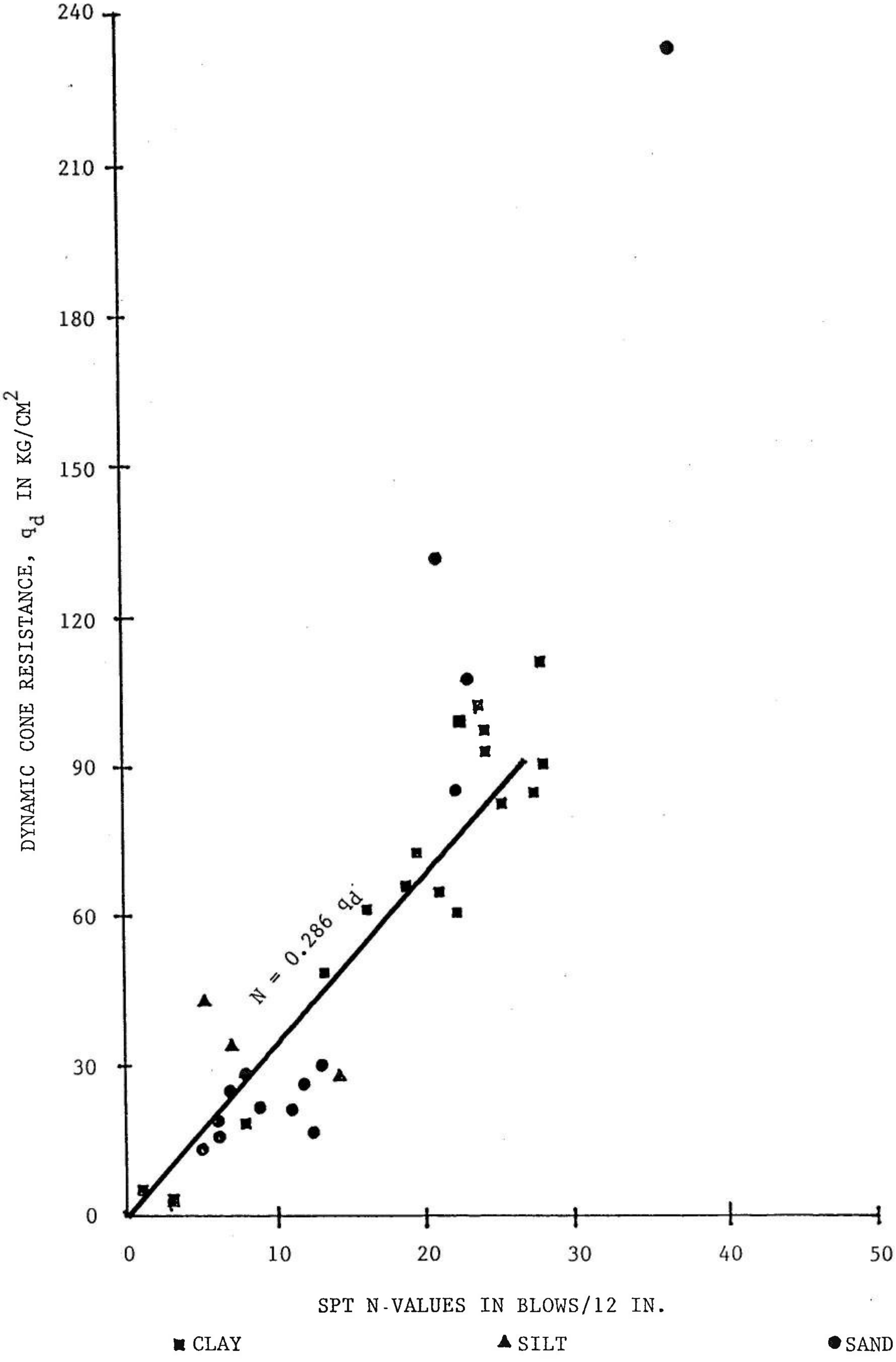

240
210
180
150
120
90
60
30
0
DYNAMIC CONE RESISTANCE, q_d IN KG/CM^2
N = 0.286 q_d
0
10
20
30
40
50
SPT N-VALUES IN BLOWS/12 IN.
CLAY
SILT
SAND

FIGURE 3

REFERENCE

Robertson, P.K.; Campanella, R.G.; and Whitman, A., "SPT-CPT Correlations," Journal of Geotechnical Engineering, Vol. 109, No. 11, (Nov. 1983), 1449-1459.

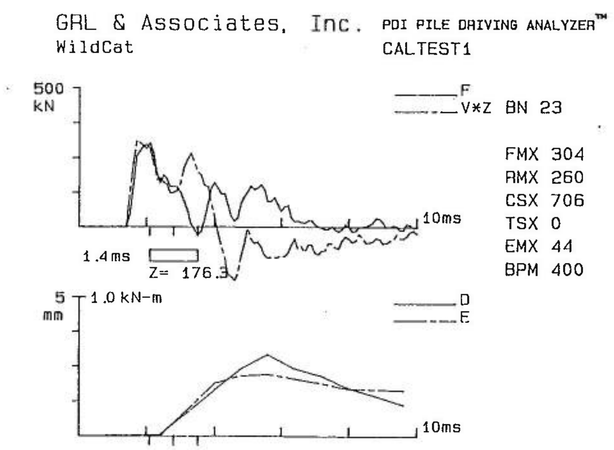
The information below was presented to the 34th Annual AEG Meeting, but was not included in the Proceedings.

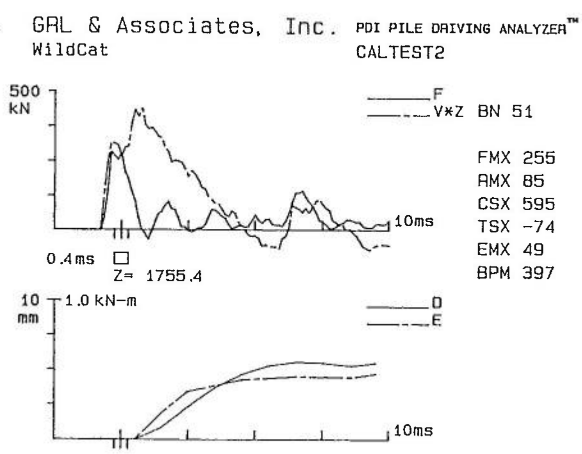
HOW MUCH ENERGY REACHES THE CONE?

ASTM D 4633-86 specifies a method for measuring the portion of a dynamic penetrometer's kinetic energy that is available to drive the tip. GRL and Associates, Inc. instrumented a WILDCAT DYNAMIC CONE PENETROMETER with two accelerometers and two strain transducers and used a pile driving analyser and their CAPWAP program to estimate the effective energy during both easy and hard driving. For easy driving (N_d = 7 blows/10 cm), 82 percent of the kinetic energy was found to be effective. For hard driving (N_d = 130 blows/10 cm), the effective energy was measured as 73 percent. In the arena of dynamic penetrometers, these effective energy percentages show the WILDCAT to be exceptionally efficient. The Force, Velocity, and Energy plots of both the hard and easy driving typical blows, and a photograph of the instrumented penetrometer are shown below.

HARD DRIVING
N_d = 130/10 cm

EASY DRIVING
N_d = 7/10 cm





$$\frac{E\ max}{E\ KE} = \frac{44}{60} = 73\%$$

$$\frac{E\ max}{E\ KE} = \frac{49}{60} = 82\%$$