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MICROCOMPUTER SOFTWARE TO COLLECT, PLOT AND INTERPRET CONE PENETRATION TEST DATA

by

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SYNOPSIS

The cone penetration test (CPT) consists of pushing an instrumented cone having an apex angle of 60 degrees into the soil and separately recording the cone resistance, qc, sleeve friction, fs, and pore pressure, u during penetration. Continuous analog signals are transmitted to the surface via a cable pre-threaded up the center of hollow cone push rods and recorded either on strip chart recorders or by a data acquisition system.

In recent years, systems have evolved to include analog to digital (A/D) converters so that the analog signals can be directly converted to digital form for data logging. The digital data is incremental in nature but typically recording all channels every 5 cm in depth. Data is typically stored on magnetic tape, floppy disk or bubble memory for future processing. Printers and plotters are also used in the field with microcomputers to calculate, print and plot data immediately after completion or during a cone sounding.

This paper will describe a microcomputer based system used to collect and process cone penetration test data in the field. The paper will also describe the software that has been developed to plot and interpret CPT data. The plotting and interpretation programs are completely user friendly and highly interactive. These programs make extensive use of menus. Examples of CPT computer plots and interpretation are also presented.

INTRODUCTION

Cone penetration testing has been carried out by the In-Situ Testing Group at the University of British Columbia (UBC) over the last nine years. Tests have been performed using a variety of cones (Fugro, Geotech, Hogentogler and UBC developed piezo cones) and a variety of data recording systems. Initially the basic cone data (q_c, f_s and u) were recorded on strip chart recorders and the data reduction performed by hand. An interactive graphics and digitizing routine was subsequently developed on the UBC mainframe computer system to provide an efficient data storage, manipulation and presentation package. Although this method was used for several years the lengthy turn around time and our lack of independence made this system less than ideal.

A significant improvement in cone electronics design was offered by Hogentogler & Co. Inc. with a downhole amplified cone and a surface 12 bit digital data acquisition system. This provided a means by which we could immediately transfer CPT data to a microcomputer for processing following a test. We have since developed amplified cones to be compatible with the Hogentogler field computer (FCS) and have been using this system for the past three years. However, the increasing number of transducers that we have designed into our cones that can not be recorded using the FCS and the special requirements of our recently developed seismic cone pressuremeter (SCPM) (Campanella and Robertson 1986) has led us to develop our own CPT data acquisition system.

This paper describes a microcomputer based system used to collect and process cone penetration test data and to control the recently developed seismic cone pressuremeter. The paper will also describe the software that has been developed to plot and interpret CPT data. Examples of CPT computer plots and interpretation will be presented.

UBC DATA ACQUISITION SYSTEM

The UBC data acquisition system (DAS) consists of an IBM PC compatible microcomputer, analog to digital (A/D) converter, depth controller board, counter/timer board and a battery backed-up power supply. A schematic layout of the system is shown in Fig. 1.

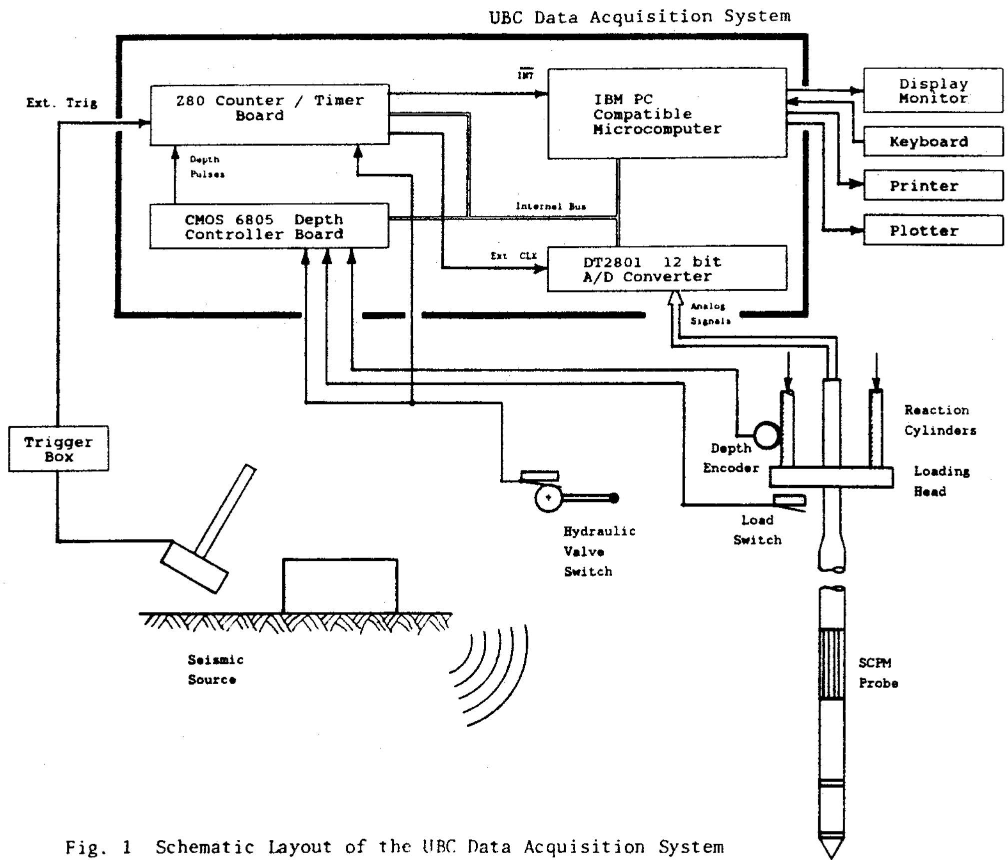


Fig. 1 Schematic Layout of the UBC Data Acquisition System

The microcomputer was assembled in-house using an IBM bus backplane and a commercially available Intel 8088 (and 8087 math coprocessor) microprocessor card. Two multifunction I/O (input/output) cards provide the 512KB of memory, real time clock, two RS232 serial ports and two parallel ports. Two half height 360KB floppy disk drives are used for data storage, however, we are currently reviewing various forms of high density storage, for example; bubble memory cartridges, permanent hard disk or hard disk card.

Graphics display is provided by an ATI Graphics Solution video adapter and any one of several types of monitors; RGB color, composite monochrome or TTL monochrome. The ATI card is a multifuntion video adapter that can display graphics in various modes, including IBM CGA hi-resolution (640 x 200 pixels, 2 colors), Plantronics hi-resolution (640 x 200 pixels, 4 colors) and Hercules Graphics mode (720 x 348 pixels, 2 colors).

The backed-up power supply is essential to ensure data integrity and continued operation despite field power supply (typically a generator) failures.

The UBC DAS is housed in an in-house built chassis and case. Unlike typical IBM PC compatible cases, all of the I/O ports and peripheral connections are located on the front panel, including power supply, video displays, keyboard, serial and parallel ports, trigger devices and probe inputs. In addition, all analog input signals are available on BNC connectors on the front panel so that the signals can be simultaneously monitored on other devices, such as, strip chart recorders and oscilloscopes.

Analog to digital conversion is accomplished using a Data Translation DT2801-A 12 bit A/D Converter board. This device can provide conversions for up to 8 channels (differential signal) with a maximum rate of 27500 samples per second. This high rate is attained by working in a DMA (direct memory access) mode which allows the DT2801-A to transfer the digital values directly to the PC memory without intervention of the microcomputer's CPU. The analog signals are converted to a 12 bit representation of their voltage. The digital values can assume 4096 states (2 raised to the 12th power) and can thus detect differences on an analog input as small as 0.024% of the selected analog input range.

Any number of channels may be selected for conversion, thereby maximizing the throughput rate for specific channels. The board can start conversions upon detection of an external trigger and timing of conversions can be controlled by an external clock. These features make the DT2801-A suitable for digitizing seismic signals.

The depth controller board is a CMOS 6805 microprocessor based interface board, designed and built at UBC, used to control the event triggering from the counter/timer board. The depth controller monitors the depth encoder, the hydraulic loading head switch and the hydraulic cylinder valve switch. Only when both the load switch and the valve switch are closed will the controller board interpret pulses from the depth encoder as actual depth increments. When the valve switch opens (as would happen at a rod break) the counter/timer board starts taking data in a time based mode so that CPT dissipations can be recorded. As the loading head is retracted to take the next cone rod the controller board counts the depth encoder pulses until the load switch opens, thereby measuring the elastic compression of the rods. As loading starts with the new rod, the closure of the valve switch places the system into a depth event mode again, however, data acquisition does not begin until the full elastic compression of the cone rods has been recovered. The depth controller has some PC accessible static RAM (random access memory) on board within which the current depth and switch status flags are stored. The depth increment used for triggering the timer board is programmable by the PC. In addition, the controller board can interface to the system hydraulics providing a pulse to trip an emergency hydraulic dump relay when a status flag is set by the PC.

The counter/timer board is a Z80 microprocessor based interface board, designed and built at UBC, providing event triggering for the DT2801-A A/D board. It is fully programmable from the IBM PC. During a CPT sounding the depth controller outputs a pulse to the counter board which in turn outputs a pulse train to the A/D board. The size of the pulse train is dependent upon the desired number of channels to be converted. When the valve switch opens during a CPT sounding the timer board automatically starts pulsing the A/D board at programmed time intervals and issues an interupt to the PC to inform it that dissipations are to be recorded. For recording seismic signals the timer board waits for an external trigger from the shear source before sending a pulse train to the A/D board. The counter/timer board is equipped with 64KB of RAM that will be used for temporary storage of seismic records when used with the downhole digital version of the SCPM. The timer board is also equipped with additional counters to be used as frequency generators for proposed signal filter cards.

UBC DATA ACQUISITION PROGRAM

The UBC data acquisition routine (UBCDAQ1) interfaces with the various components of the data acquisition system to provide a means of collecting, displaying and storing CPT test data. It also communicates with the seismic cone pressuremeter in order to toggle the channel select relays on the downhole amplifier boards. The majority of the program has been written in Microsoft C (Version 4.0) with some small sections being written in 8088 assembly language.

The program operates in four modes; cone penetration, dissipation, seismic and pressuremeter. During cone penetration mode the routine records the CPT channels at the desired depth increments automatically switching to dissipation mode when the hydraulic valve swith opens. The user must request to enter either seismic or pressuremeter mode at which time UBCDAQ1 must pulse the SCPM channel select relays to put the probe into the correct mode. In seismic mode UBCDAQ1 must also program the A/D board to activate the external trigger. The routine is responsible for programming the counter/timer board with the appropriate timing parameters and the depth controller board with the desired depth increment.

In all modes except seismic the program can display the data in real time. The seismic data can only be shown after the entire seismic record has been stored in memory.

The display is divided into four areas; the output window, the data window, the status window and the graphical display window (Fig. 2). The status window displays the current mode and the current status within that mode.

The output window displays the current time or depth and the number of records that have been written to the output devices for the current mode.

The data window displays the current values of the channels in one of four formats; A/D integer values, A/D hexadecimal values, voltages or engineering units.

Within the graphical display window up to three plotting areas can be defined (Fig. 2). For each plotting area any channel, time or depth can be designated as the independent variable and any other three channels may be selected as the dependent variables. During the test the dependent variables will be plotted against the independent variable in each of the defined plotting areas. An example of this is shown in Fig. 2b where in the top plotting area the traditional pressuremeter curve (arm displacement vs total pressure) is recorded. In the bottom two areas the parameters from the top area are recorded against time. Automatic expansion of the independent variable scale occurs when the test reaches the current scale limit.

Each of the display windows for each mode is independently controlled through menu selections. The frequency with which the recorded data is written to disk and to the printer can also be defined by the user.

UBC CPT PLOTTING PROGRAM

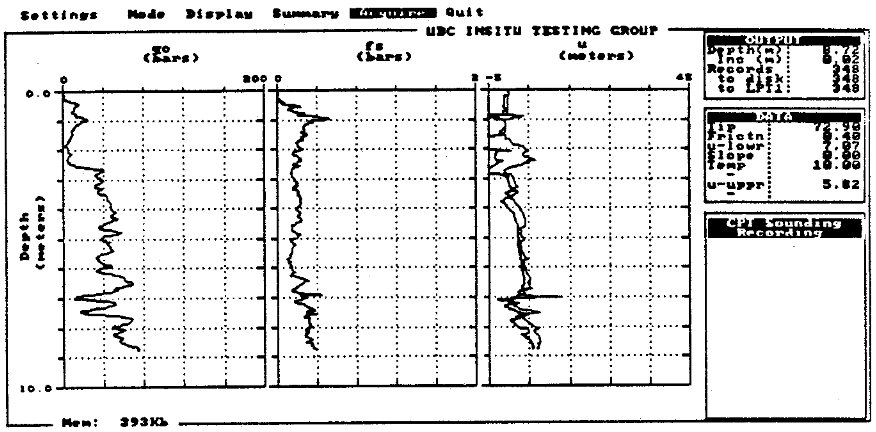
In order to present CPT data UBC has developed a plotting program (CONEPLOT) to output various CPT parameters to a Hewlett-Packard HP7470A plotter. The program was originally developed on an OSBORNE 1 portable computer using the Microsoft MBASIC interpreter. It was later transported to an IBM PC to run under the Microsoft BASICA interpreter. To increase execution speed it was converted to an executable form using the IBM BASIC Compiler Version 2.0. The program runs in an interactive manner in which the user responds to prompts displayed on the screen. The operator can obtain the desired plot based on the following options:

i) horizontal or vertical page orientation
ii) a choice of from 1 to 3 or 1 to 5 variables on a page depending on the plot orientation
iii) plots in terms of CPT data corrected or uncorrected for pore pressure effects (Campanella and Robertson 1981)
iv) user defined scales
v) scale changes between plotted pages
vi) specification of pages to be plotted
vii) various line types
viii) overlays of data from several files

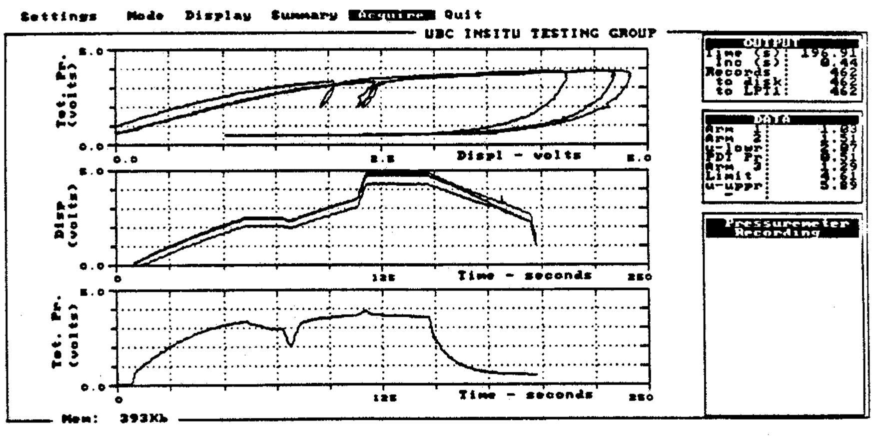
A typical plotted output is shown in Fig. 3.

CONEPLOT accepts two data file formats; the default format produced by the Hogentogler FCS and a slight variaton to this produced by a UBC CPT data processing routine CPTCORR. This program is used to adjust the CPT data for temperature offsets (Greig 1985) and pore pressure effects (Campanella and Robertson 1981). Although the data files may contain inclination and temperature data, these parameters can not be plotted from CONEPLOT (without some data file manipulation and changes to the CONEPLOT support files) due to the memory limitations of the interpreters and compiler used to develop the program. In addition, the program assumes a constant depth increment for each data record rather than using memory to store the depth values. Because of the development history of the routine, CONEPLOT does not provide an on screen graphical display for previewing plots before sending the output to the plotter.

An updated version of CONEPLOT, which is nearing completion, will make extensive use of on screen graphics and use as much of the computer's available memory as required. The program has been completely rewritten in Microsoft C (version 4.0). Pop-up menus allow the user to select the data file, recall default set-up parameters, specify axis scales, select the parameters to be plotted and preview the plot before sending the output to the plotter. All of the parameters in the data file may be plotted and user defined file formats may be specified. In addition, the data file records need not be at constant



a) cone penetration test mode



b) pressuremeter test mode

Fig. 2 Typical Displays from the UBC Data Acquisition System increments as the actual depth values are used for plotting. The program supports several popular display adapters; IBM color graphics (CGA), Hercules monochrome graphics (HGA) and IBM Enhanced graphics (EGA). Screen dumps to several types of dot matrix printers including the HP Laser Jet are also supported. An example of a profile plotted on the screen is shown in Fig. 4a and the same plot with one of the menus activated is shown in Fig. 4b.

UBC CPT INTERPRETATION PROGRAM

UBC has developed a program (CPTINTR1) to provide a basic interpretation of cone penetration test data based on the interpretation and correlation methods presented by Robertson and Campanella (1984). The program is written in compiled BASIC (IBM BASIC Compiler Verson 2.0) and runs in an interactive manner where the user selects available options from menus. The program provides a tabulated output of estimates of soil parameters based on cone bearing (q_c) and friction ratio (R_f) values averaged over a user selected depth range. A typical output is shown in Fig. 5. Plotted output of the parameter estimates is not supported. However, the program does provide an option to plot all of the available correlation methods on an HP7470A plotter.

Table I summarizes the interpreted soil parameters and the correlation options available from CPTINTR1. Soil classification is based on the relationship between cone bearing and friction ratio proposed by Robertson and Campanella (1983) shown in Fig. 6a. The various correlations for relative density represent the results of chamber tests on sands of different mineral composition and compressibility. For estimating friction angle Robertson and Campanella (1983) proposed an average empirical relationship derived from a review of calibration chamber tests. The other two methods are theoretical relationships based on bearing capacity theory. Estimates of SPT N values are made from q_c/N ratios assigned to each zone of the classification chart which reflect the increase in q_c/N with increasing grain size as reported by Robertson et al. (1983).

It must be emphasized that the interpretations produced by CPTINTR1 should be used only as a guide to soil behaviour type and parameter values. Many of the correlations may require slight adjustments based on local experience for specific soil types.

The authors have found from their experience that it is not always possible to clearly identify a soil type based solely on cone bearing and friction ratio. The authors recommend the use of all three pieces of data

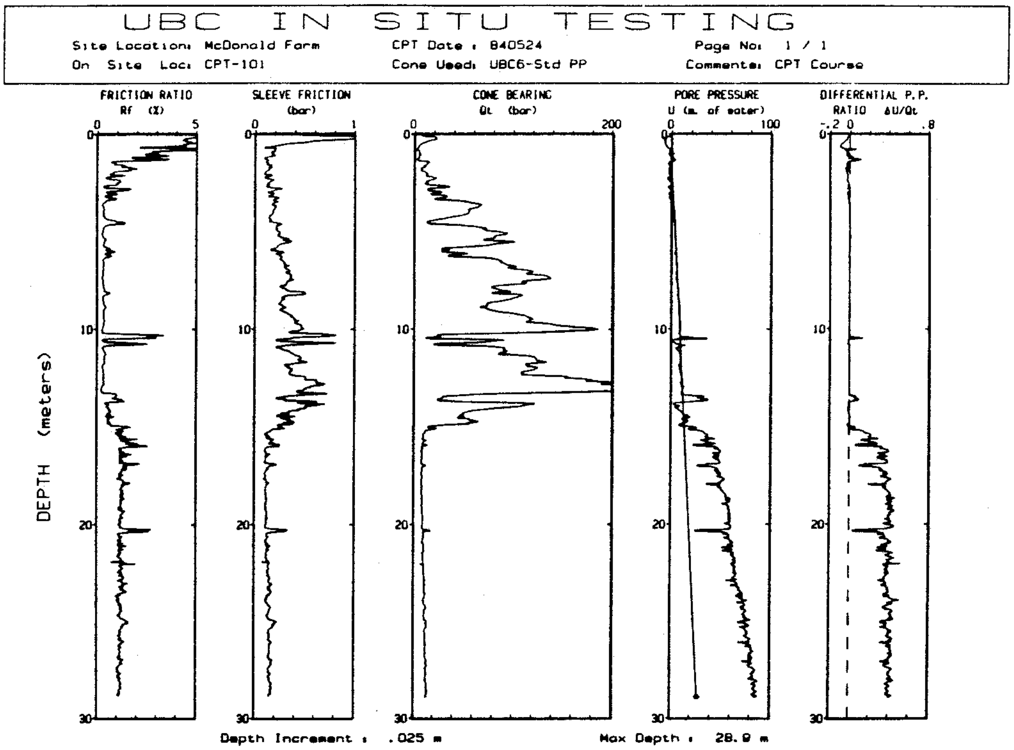
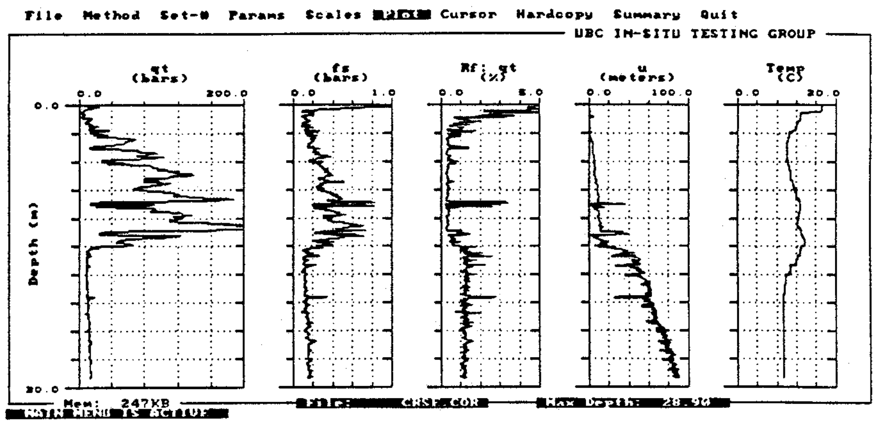
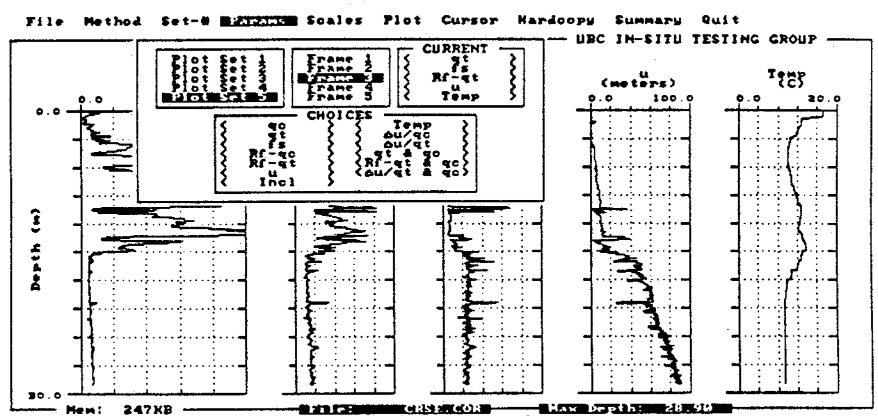


Fig. 3 Typical Plotter Output from the UBC CPT Plotting Program



a) typical plot



b) display with parameters menu open

Fig. 4 Typical Displays from the Recently Updated CPT Plotting Program

Table I

Correlations Available from the UBC CPT Interpretation Program

1) Soil Behaviour Type: - Robertson and Campanella 1983

2) Equivalent Relative Density :

- i) Ticino Sand - Bellotti et al. 1985
- ii) Hokksund Sand - Bellotti et al. 1985
- iii) Ottawa / Hilton Mines Sands - Schmertmann 1976
- iv) All Sands (average) - Jamiolkowski et al. 1985

3) Angle of Internal Friction

- i) Robertson and Campanella 1983
- ii) Durgunoglu and Mitchell 1975
- iii) Janbu and Senneset 1974 - Beta=+15,0, and -15 degrees

4) Equivalent SPT N value - Robertson et al. 1983

5) Corrected SPT N1 value - N1=Cn*N (where Cn=SIG^(-.7) and SIG is in Kg/cm^2)

6) Cyclic Stress Ratio (CSR) to cause liquefaction (M=7.5) - Seed et al. (1983)

7) Undrained Shear Strength (Su) - Su=(Qc-SIGV)/Nk where SIGV is the total overburden stress

UBC IN SITU TESTING

Site : McDonald Farm
On Site Loc: CPT-101
Comments : CPT Course
Tot. Unit Wt. (avg) : 18 kN/m^3

CPT Date : 840524
Cone Used : UBC6-Std PP
Water table (meters) : 1

DEPTH (meters)	(feet)	Qc (avg) (bar)	Fs (avg) (bar)	Rf (avg) (%)	SIGV' (kPa)	SOIL BEHAVIOUR TYPE	Eq - Dr (%)	PHI deg.	SPT N	SPT N1	CSR
0.25	0.82	18.02	0.95	5.26	2.25	clay	UNDFND	UNDFD	18	>50	UNDF
0.50	1.64	12.65	0.57	4.52	6.75	clay	UNDFND	UNDFD	13	48	UNDF
0.75	2.46	4.93	0.19	3.91	11.25	clay	UNDFND	UNDFD	5	15	UNDF
1.00	3.28	4.81	0.18	3.62	15.74	clay	UNDFND	UNDFD	5	12	UNDF
1.25	4.10	5.39	0.15	2.69	19.02	clay	UNDFND	UNDFD	5	12	UNDF
1.50	4.92	9.80	0.12	1.22	21.06	clayey silt to silty clay	UNDFND	UNDFD	5	11	UNDF
1.75	5.74	10.78	0.14	1.32	23.11	clayey silt to silty clay	UNDFND	UNDFD	5	11	UNDF
2.00	6.56	9.74	0.12	1.20	25.16	clayey silt to silty clay	UNDFND	UNDFD	5	10	UNDF
2.25	7.38	16.03	0.12	0.74	27.20	sandy silt to clayey silt	UNDFND	UNDFD	6	12	UNDF
2.50	8.20	16.19	0.15	0.94	29.25	sandy silt to clayey silt	UNDFND	UNDFD	6	12	UNDF
2.75	9.02	23.99	0.13	0.54	31.30	silty sand to sandy silt	40-50	38-40	8	14	.23x
3.00	9.84	19.61	0.19	0.99	33.34	sandy silt to clayey silt	UNDFND	UNDFD	8	13	UNDF
3.25	10.66	26.91	0.17	0.62	35.39	silty sand to sandy silt	40-50	38-40	9	15	.23x
3.50	11.48	36.99	0.21	0.56	37.44	silty sand to sandy silt	50-60	40-42	12	20	.30x
3.75	12.30	65.28	0.19	0.29	39.48	sand to silty sand	60-70	42-44	16	26	.27
4.00	13.12	56.89	0.19	0.33	41.53	sand to silty sand	60-70	42-44	14	22	.23
4.25	13.94	48.58	0.16	0.33	43.58	sand to silty sand	50-60	40-42	12	18	.19
4.50	14.76	23.54	0.15	0.63	45.62	silty sand to sandy silt	<40	36-38	8	12	.20x
4.75	15.58	35.87	0.23	0.63	47.67	silty sand to sandy silt	40-50	38-40	12	17	.26x
5.00	16.40	74.22	0.22	0.30	49.72	sand to silty sand	60-70	42-44	19	26	.28
5.25	17.22	88.69	0.24	0.27	51.76	sand	70-80	42-44	18	24	.26
5.50	18.04	80.71	0.31	0.38	53.81	sand to silty sand	70-80	42-44	20	27	.29
5.75	18.86	82.14	0.27	0.33	55.86	sand to silty sand	60-70	42-44	21	27	.29
6.00	19.69	35.94	0.19	0.54	57.90	silty sand to sandy silt	40-50	38-40	12	16	.24x
6.25	20.51	42.06	0.25	0.60	59.95	silty sand to sandy silt	40-50	38-40	14	18	.27x
6.50	21.33	75.76	0.26	0.35	62.00	sand to silty sand	60-70	40-42	19	24	.25
6.75	22.15	93.08	0.30	0.32	64.04	sand	70-80	42-44	19	23	.24
7.00	22.97	105.32	0.32	0.30	66.09	sand	70-80	42-44	21	26	.27
7.25	23.79	120.42	0.34	0.28	68.14	sand	70-80	42-44	24	29	.32
7.50	24.61	133.98	0.36	0.27	70.18	sand	80-90	42-44	27	32	.36
7.75	25.43	108.25	0.32	0.29	72.23	sand	70-80	42-44	22	25	.27
8.00	26.25	83.02	0.29	0.34	74.28	sand to silty sand	60-70	40-42	21	24	.25
8.25	27.07	94.71	0.45	0.47	76.32	sand to silty sand	60-70	40-42	24	27	.29
8.50	27.89	101.83	0.29	0.28	78.37	sand	70-80	42-44	20	23	.24
8.75	28.71	79.56	0.26	0.32	80.42	sand to silty sand	60-70	40-42	20	22	.23
9.00	29.53	72.85	0.28	0.39	82.46	sand to silty sand	60-70	40-42	18	20	.21
9.25	30.35	93.45	0.30	0.33	84.51	sand	60-70	40-42	19	20	.21
9.50	31.17	116.53	0.38	0.33	86.56	sand	70-80	42-44	23	25	.26

Dr - All sands (Jamiolkowski et al. 1985) PHI - Robertson and Campanella 1983 CSR: Seed et al. 1983 - M=7.5

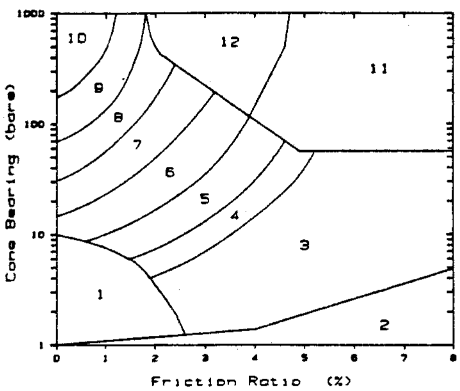
x - Seed's correction of 7.5 blows/foot has been applied to N1

**** Note: For interpretation purposes the PLOTTED CPT PROFILE should be used with the TABULATED OUTPUT from CPTINTR1 (v 3.04) ****

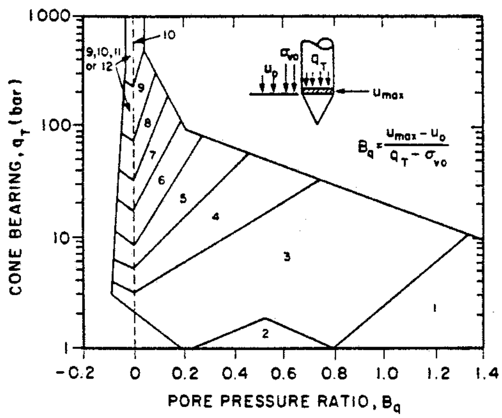
Fig. 5 Typical Output from the UBC CPT Interpretation Program

(q_t, u, f_s) to define soil behaviour type. A first attempt at defining such a system is shown in Fig. 6.

The UBC CPT interpretation program is currently being revised to incorporate this new classification system. In addition, the program is being revised to produce a graphical output of the interpretation results and to allow user defined changes to the correlation methods in order to reflect local experience.



a) cone bearing and friction ratio



b) cone bearing and pore pressure parameter Bq

Zone	Qc/N	Soil Behaviour Type
1)	2	sensitive fine grained
2)	1	organic material
3)	1	clay
4)	1.5	silty clay to clay
5)	2	clayey silt to silty clay
6)	2.5	sandy silt to clayey silt
7)	3	silty sand to sandy silt
8)	4	sand to silty sand
9)	5	sand
10)	6	gravelly sand to sand
11)	1	very stiff fine grained (*)
12)	2	sand to clayey sand (*)

(*) overconsolidated or cemented

Fig. 6 Proposed Soil Behaviour Type Classification Systems from CPTU Data
(adapted from Robertson et. al, 1986)

SUMMARY

This paper has presented a brief history of the development of a microcomputer based data acquisition system (DAS) for collecting CPT data. It has also described the components of the system and some of the important details that had to be incorporated in its design. The system is based on an IBM PC compatible microcomputer and uses three special purpose plug-in boards to provide the analog to digital conversions, the event triggering and the timing of the data acquisition. The system has been designed to be able to provide the high speed data aquisition required for recording seismic records as well as the low speed required for recording dissipations. To ensure accurate depth measurements a depth encoding system accounts for the elastic compression of the cone rods during a CPT sounding.

The data acquisition software (UBCDAQ1) is the interface between the system components and the user providing a means of collecting, displaying and recording test data. UBCDAQ1 is designed to control data acquisition for pressuremeter tests, seismic cone tests and for cone penetration tests including the automatic switching to a dissipation recording mode whenever a pause occurs during a CPT sounding. Except during a seismic cone test, UBCDAQ1 displays the data in real time in various numerical or graphical forms as specified by the user.

The UBC CPT plotting routine (CONEPLOT) provides plotted output of CPT data on an HP7470A plotter. The user has several options for the style of presentation and has great flexibility in the choice of scales and parameters to be plotted. An updated version, which is nearing completion, makes extensive use of on screen graphics and a pop-up menu user interface.

The UBC CPT interpretation program (CPTINTR1) provides a basic interpretation of cone penetration test data based on the cone bearing and friction ratio. The program gives a tabulated output of soil behaviour type, relative density, friction angle, SPT N values, cyclic stress ratio to cause liquefaction and undrained shear strength of clay. UBC is currently updating the program to incorporate pore pressure measurements in the interpretation methods and to provide the user the ability to modify correlations to reflect local experience.

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