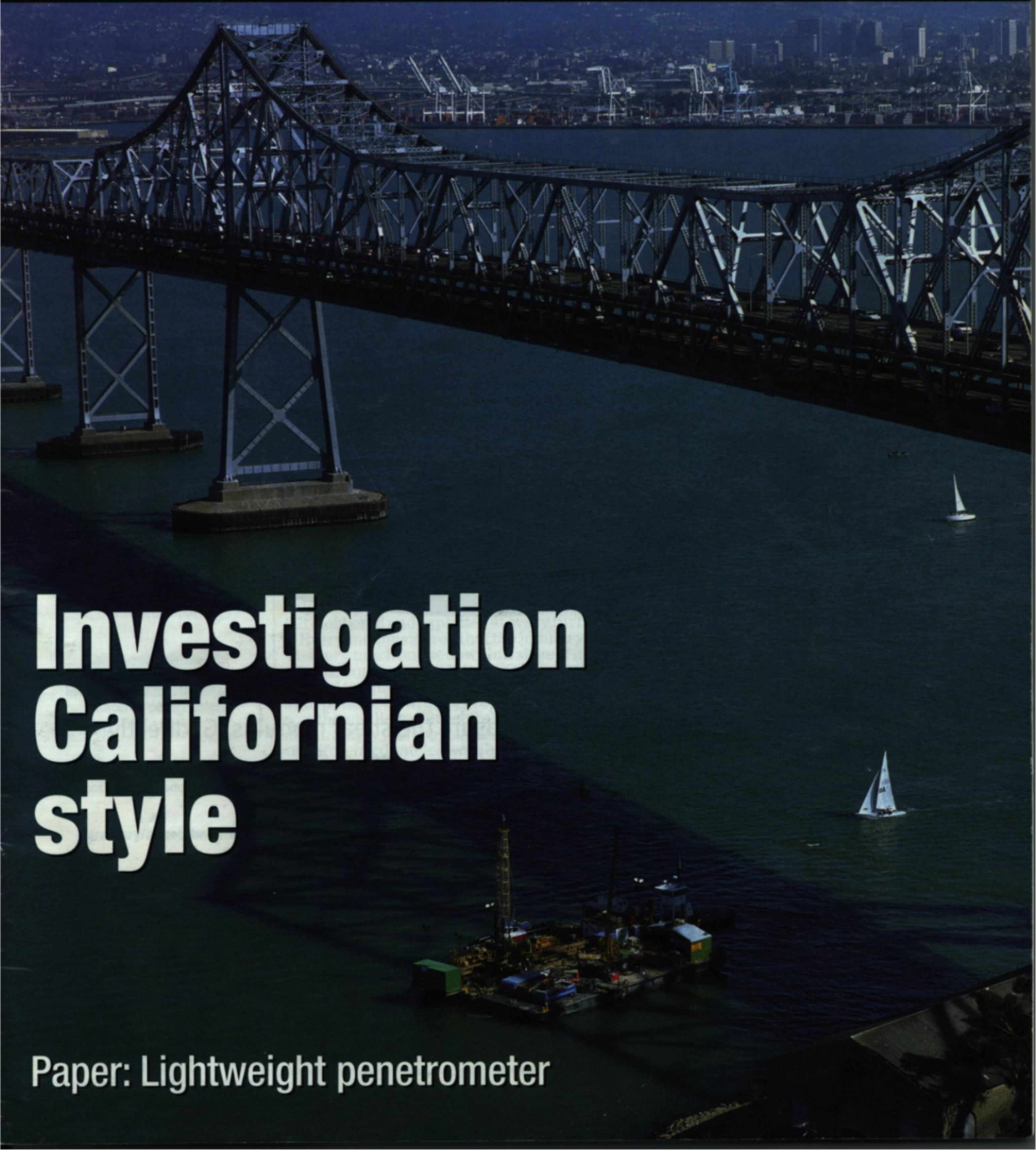
September 1999

An Emap Construct Publication £5/$8

Ground Engineering



Investigation Californian style

Paper: Lightweight penetrometer

The Panda lightweight penetrometer for soil investigation and monitoring material compaction

by DD Langton, Soil Solution

Abstract

Dr Roland Gourves, the principal lecturer in soil mechanics at CUST, Blaise Pascal University, Clermont-Ferrand, France has designed and been developing the Panda (a lightweight handheld dynamic cone penetrometer for testing soils and materials) since 1991. It has become widely used and accepted across France, parts of central Europe and in small numbers around the world.

Since its initial development, the Panda has been continuously developed to be used to test the compaction of fill in earthworks, through software analysis as well as in site investigation. Trials have been carried out at nine sites across the UK (both working sites as well as Building Research Establishment test bed sites) to clarify the usefulness and reliability of the software analysis and correlations for use in the UK.

The principle of the Panda

The Panda is a lightweight (20kg) dynamic cone penetrometer, which uses variable energy and can be operated by one man to test soils in almost any location to a depth of 6m. **Table 1** shows the dimensions of the Panda compared to specification for DPH and SPT according to BS1377:Part 9:1990.

The blow from a hammer to the head of the tool provides the energy input (**Figure 1**). A unique microprocessor records two parameters for each blow of the hammer, the speed of impact and the depth of cone penetration, by measuring the output from two sensors. An accelerometer on the head of the tool measures the speed of impact of the hammer while the depth of penetration is measured by a retractable tape. The dynamic cone resistance (q_d) and current depth are then calculated and displayed in real time data on the screen of the microprocessor. q_d is calculated using the Dutch formula (Cassan M, 1988) which is the most appropriate formula for this apparatus and has been modified to the following:

$$q_d = \frac{1}{A} \cdot \frac{1/2MV^2}{x_{90^\circ}} \cdot \frac{1}{1+\frac{P}{M}}$$

x_{90° penetration due to one blow of the hammer (90° cone)
A is the area of the cone
M is the striking mass
P is the struck mass
V is the velocity of impact (of the hammer)

It should be noted that the expression for energy used in the formula ($1/2MV^2$) is for kinetic energy, as the energy input is variable because it is delivered manually by the blow of a hammer. The test values recorded by the microprocessor can be transferred to a computer to plot the values of cone resistance against depth using the Panda Windows software (**Figure 2**).

Although there are many applications of the Panda, they can be separated into two main categories. First, in monitoring the compaction of materials used as fill both in trenching works and to structures as well as cut and cover or ground improvement operations. Second, the Panda can be used for all types of site investigation and is especially useful where access is restricted, for example for slope stability studies along road and railway cuttings and embankments and for testing the strength of the pavement and permanent way. Other notable applications include investigations for low-rise developments and temporary structures and in the safety of heavy plant. The Panda has the capability of reaching between 4m and 6m in soils of up to 20MPa to 30 MPa resistance and even deeper where circumstances allow.

Table 1: Dimensions of dynamic probe apparatus		DPH BS 1377 (1990)	SPT BS 1377 (1990)	PANDA		
Hammer:	Mass (kg)	50	63.5	2		
	Standard drop (mm)	500	760	Variable (measured)		
Anvil:	Mass (kg)	18	15-20	2.16		
Cone:	Mass (cm²)	15	–	2	4	10
	Angle (°)	90	–	90	90	90
	Diameter (mm)	43.7	25 (shoe)	16	22.5	35.7
	Tip length	21.9		1.1	1.6	2.5
Extension rods:	Mass (kg)	6	<10kg/m	0.586		
	Length (m)	1	–	0.5		
	Diameter	35		14		

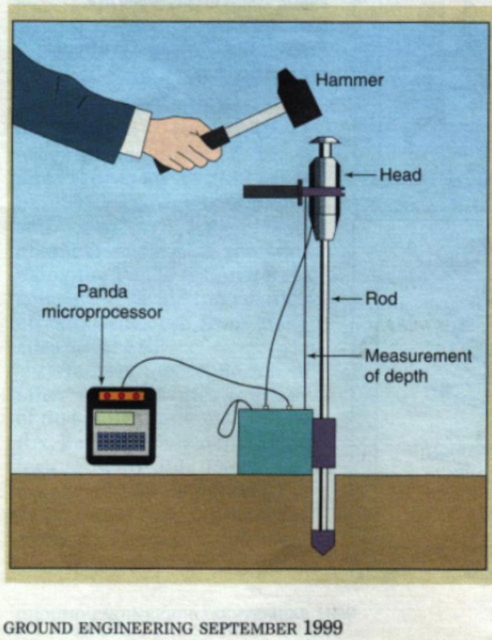


Figure 1 (LEFT): The Panda during testing.

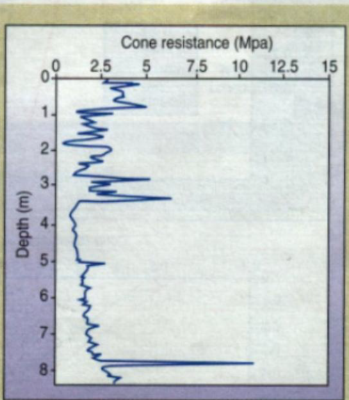
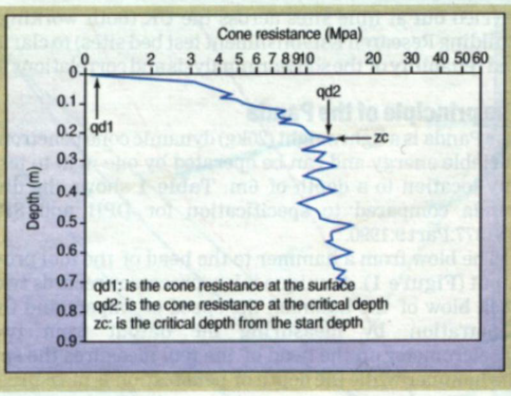


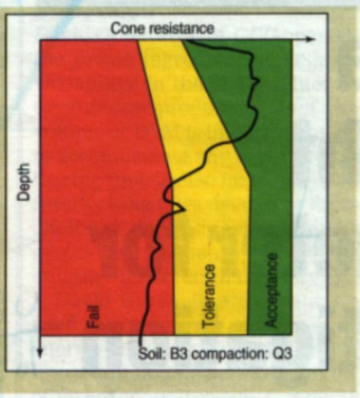
Figure 2: Example of a test carried out in loose sand and soft silt.

Interpretation of the Panda results for monitoring the compaction of fill

Interpretation of results from a Panda test when monitoring the compaction of fill can be done easily using a simple method available in the Panda software. The method, which is the result of a long period of scientific research at CUST, Blaise Pascal University in Clermont Ferrand (Zhou 1997) involves choosing the appropriate material (used during the fill operation) from a list available in the software based upon a simple classification system using plasticity and grain size distribution.

Figure 3: The two lines of tolerance relate to the chosen density of a material. Figure 4 (FAR RIGHT): Model for cone resistance and depth in an homogeneous soil at a given level of compaction.





With 18 different natural soils to choose from, three different levels of compaction (95% of optimum Proctor, 98.5% of optimum Proctor and 97% of modified Proctor), and a choice of moisture contents (either wet or dry of the optimum moisture content), over 130 different choices of materials are available in the software. After the appropriate material has been chosen the software then plots two "lines of tolerance" on the graph which relate to a chosen density for that material (**Figure 3**).

The two lines are known as the line of reference (green line) and the line of failure (red line). The green line represents the chosen level of compaction for the material and hence values plotting to the right of this line are greater or equal to that level of compaction. The red line represents a 2% to 3% margin of error below which the compaction of the material should not fall. The area between the two lines is known as the area of tolerance.

How are the lines of tolerance defined?

These lines of tolerance can be defined because a relationship exists between the degree of compaction γd (or experimental dry density as a percentage of maximum dry density) and the dynamic cone resistance for a given material. Following research (Zhou 1997) a model has been developed for cone resistance and depth, in a homogeneous soil at a given level of compaction (see **Figure 4**). It was found that soil of given properties compacted evenly to a given density, consistent values of zc, q_{d1} and q_{d2} can be defined.

q_{d1}: is the cone resistance at the surface

q_{d2}: is the cone resistance at the critical depth, which is the maximum value of cone resistance for a given material at a given level of compaction.

zc: is the critical depth measured from the surface at which the maximum cone resistance q_{d2} is found.

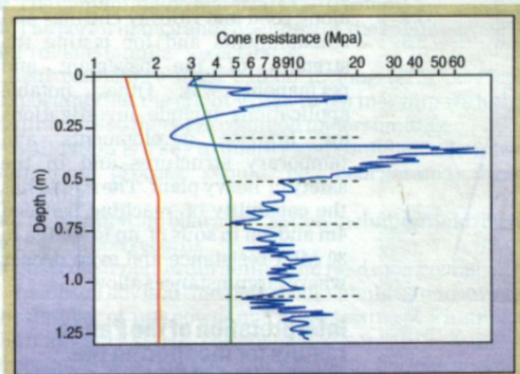
Using this technique soils and materials from across the classification spectrum can be taken and compacted to varying densities and the average values of zc, q_{d1} and q_{d2} can easily be calculated and hence the lines of reference and failure defined for each material at each different level of compaction.

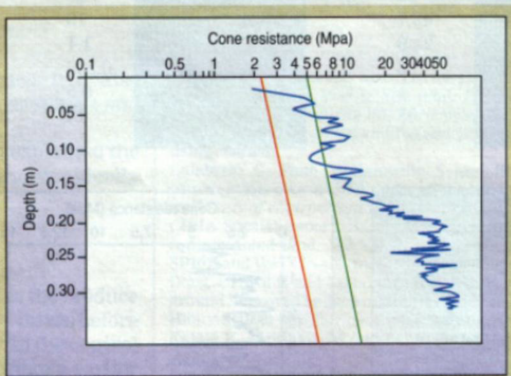
Figures 5 to **8** show examples of compaction monitoring from different sites. **Figures 5** and **6** show tests carried out with the Amec/Tarmac joint venture at Manchester Airport second runway. **Figure 5** shows the results of a test carried out in cohesive fill used in the cut and cover operation, the green line in this case represents 95% maximum density for a medium to high plasticity clay. The layer boundaries are well defined by a reduction in cone resistance (indicated by dashed lines); the increase in cone resistance at 0.15 and between 0.3m and 0.5m is due to modification of these layers using quicklime.

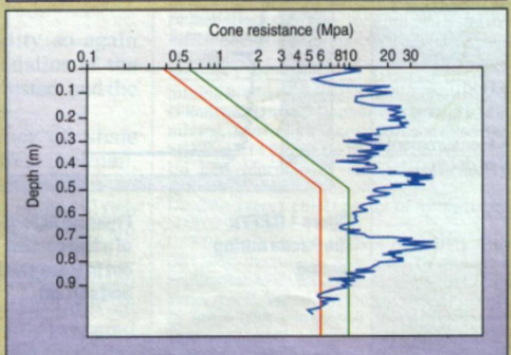
Figure 6 represents a test carried out on the same site in granular backfill to the new A538 tunnel. The shape of the plot indicates the material was well compacted using the correct layer thickness as layer boundaries are poorly defined. The green line of reference represents 98% maximum density, which remains straight, as the test did not go beyond the critical depth (q_{d2}). Nuclear Density Gauge results showed the material was between 98% and 100% maximum density.

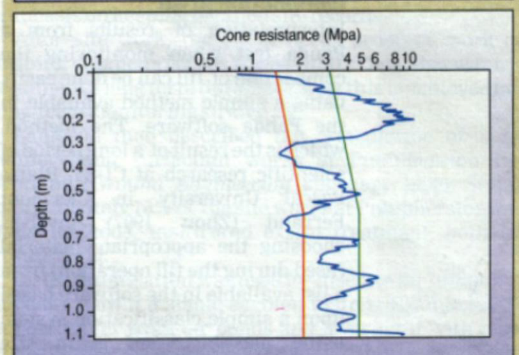
Figures 7 and **8** are both good examples of where oversized layers have been used when compacting a material. **Figure 7** is a test carried out on the clay lining of a landfill site using a high plasticity clay compacted wet of the optimum moisture content. Laboratory tests on samples taken showed the density of the material to be between 95% and 98% of the maximum. The green line of tolerance plotted on the graph again represents 98% maximum density for a high plasticity clay wet of the optimum moisture content. On this particular site however, the density of the material is less important than the permeability and integrity of the lining, which was found to be sufficient.

Figure 8 is a plot of the results of a test carried out in a trench in a carriageway for one of the utility companies operating in the Midlands. In this case the green line of tolerance represents 95% maximum density and this level of compaction appears to have been achieved, however layer thicknesses of over 300mm have been used, leaving weak layers which could lead to settlement and ultimately lead to defects in









Clockwise from top left:
Figure 5: Test in cohesive fill at Manchester Airport.
Figure 6: Test in granular fill at Manchester Airport.
Figure 7: Test in clay lining of a landfill site.
Figure 8: Test carried out in a trench in a carriageway.

Table 2: Basic soil properties of BRE test sites

Site	Depth m	Description	Density Mg/m3	Water content %	Ip %	Clay content %	Cu kPa
Cowden	1		2.1	18	20	30	-
(North Humberside)	2	Weathered brown stiff stoney clay	2.2	17	22	31	-
	3	glacial till. Some fissures	2.2	17	19	30	135
	4		2.2	17	19	32	118
	5		2.2	18	16	31	115
Canons Park	1		1.95	20	34	-	40
(North London)	2	Medium dense gravel and sand	1.95	30	42	43	-
	3	Firm to stiff chocolate brown silty	1.95	26	46	-	70
	4	fissured clay	1.95	26	52	40	75
	5	Stiff brown silty fissured clay	2	30	48	-	125
	6		2	28	35	41	115
Bothkennar		Soft-firm fissured black organic					
(south bank of the Forth river)	2-5	very silty clay with some small	1.68	56	36	40	20
		pockets of light brown silty clay					
Pentre	2	Very stiff to stiff brown/grey silty	1.89	31	30	38	80
Severn Valley (Shropshire)	3	clay	1.97	-	-	28	50
	4		1.84	30	24	16	40
	5	Soft grey foliated very silty clay	1.95	36	16	9	27
BRE Garston	0-1	Seasonally weathered	-	-	-	-	110
(Watford)	2	Stiff brown-grey mottled clay	2.2	16	28	42	175
	3	erratics 1-30mm	2.2	17	29	41	240
	4		2.2	17	29	42	250
Vale of York	0.5	Firm to stiff brown silty very sandy	-	15	12	-	70
	1	clay some fine to coarse gravel and	-	-	-	-	51
	1.8	occasional cobbles, becoming	-	15	12	-	33
	2.4	softer below 1.3m	-	-	-	-	20

the reinstatement.

Interpretation of the Panda results for site investigation

The output of the Panda is given in MPa, which, although directly related to values of static cone resistance, requires some correlations to other more conventional design parameters such as SPT, other types of DCP, CBR and undrained shear strength. Correlations to these parameters already exist thanks to experience and research carried out to date in France, however some clarification of these correlations was required in typical soils found in the UK.

Building Research Establishment test bed sites

The Building Research Establishment (BRE) has a number of well-documented test bed sites across the country, representing various soil types in different geographical areas (**Table 2** and **Figures 9** to 13, Butcher et al, 1995). Typical continuous soil profiles have been obtained at each of the sites using the Panda (**Figure 9**) to compare it to the information already collected from these sites by the BRE.

Data was also collected at other non-BRE sites courtesy of Structural Soils and Murray Rix. It must be noted that when testing with the Panda, an over-sized hole is produced to avoid the effects of rod friction, although this does become unavoidable at depth.

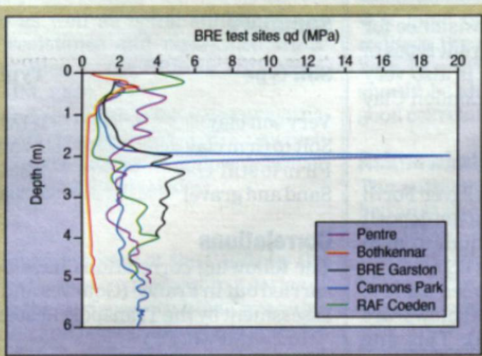


Figure 9: Typical continuous soil profiles at BRE sites.

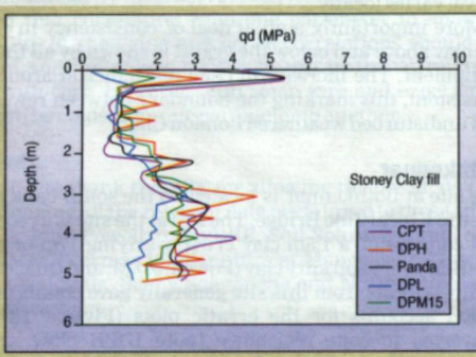


Figure 10: Cowden qd vs depth.

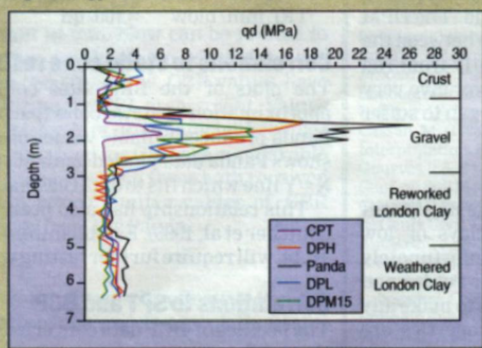


Figure 11: Canons Park qd vs depth.

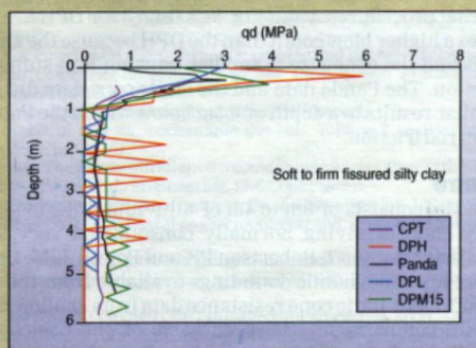


Figure 12: Bothkennar qd vs depth

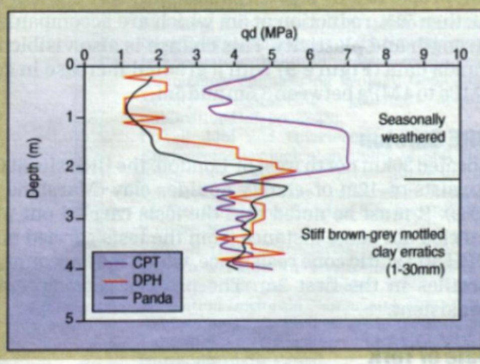


Figure 13: BRE Garston qd vs depth.

However, while testing at each of the sites the rod friction was assessed every 0.5m and the test terminated when it was considered that any rod friction was adding to the values of cone resistance.

Analysis of the results

The data available from the BRE included static cone resistance (CPT) and dynamic sounding tests (DPL, DPM and DPH). The results from the static cone tests can be plotted directly against the Panda results as they effectively give the same parameter. The results from the other tests can be plotted either as blows/10cm or as dynamic cone resistance (q_d) using the Dutch formula, although the energy input for the equation is for potential energy (MgH) and not kinetic energy.

Cowden

The overconsolidated glacial tills at Cowden have been studied for over 20 years and their properties are well documented (Marsland A and Powell JJM, 1985). For the depths tested, the soil consists of a stiff till with gravel of intermediate plasticity. **Figure 10** shows profiles to a depth of 5m for each of the apparatus, each showing a similar profile with gravel layers at 2.2m and 3m.

Canons Park

All of the testing carried out at Canons Park (**Figure 11**) resulted in very similar profiles, all reflecting dense gravel overlying London Clay (high plasticity firm to stiff clay). The dynamic soundings all reflect the different soil profiles well, with the more lightweight equipment logically giving the highest blow counts and more detail. Although both the depth of the base of the gravel layer and the values for cone resistance vary considerably within the gravel, this can be expected in such a variable material, and it is known that the depth of the base of the gravel varies locally.

More importantly, a great deal of consistency in cone resistance for the clay above and below the gravel is shown by all the different types of equipment. The increase in cone resistance at around 5m is also very consistent, this marking the boundary between reworked London Clay and undisturbed weathered London Clay.

Bothkennar

The site at Bothkennar is located on the south bank of the River Forth close to Kincardine Bridge. The soil at the site is a recent marine deposit and consists of a 1.5m clay crust overlying 17m of a medium to high plasticity very soft silty clay (Powell, J.J.M. and Quarterman RST, 1995).

Blow counts from this site generally gave counts of between 0 and 3, which accounts for the erratic plots (**Figure 12**) when blows are converted to cone resistance (note 1DPH blow = 2MPa). This site highlights the lack of definition shown by heavier equipment in very soft soils. It must be noted that according to BS 1377 and recommended testing procedures, values of less than 3 for DPH are invalid. The DPM gives a higher blow count than the DPH because the annulus between the rods and the cone size is smaller, causing it to suffer greatly from rod friction. The Panda data and the static cone data did however give very similar results to a depth of 4.5m below which the Panda began to suffer from rod friction.

Pentre

The site consists of 3m to 4m of alluvium (intermediate plasticity stiff silty clay) overlying normally consolidated very silty clays of low plasticity (Lunne T, Robertson PK and Powell JJM, 1997). Unfortunately there are no dynamic soundings available from the site at Pentre and insufficient static cone resistance data from shallow depths to make any useful comparisons. However, some of the basic soil properties are detailed in **Table 1** along with values for undrained shear strength.

The transition from the alluvium to the silty clay can be seen in the soil properties by a 50% reduction in clay content at around 4m and a further 50% reduction at 5m which are accompanied by reduced shear strength and plasticity. This change is also visible in the profile of the Panda data (**Figure 9**) with a gradual increase in cone resistance from 2MPa to 4MPa between 3.5m and 5m.

BRE Garston

Located 30km north west of London, the BRE site at Garston (**Figure 13**) consists of 12m of chalky boulder clay (Marsland A and Powell JJM, 1989). It must be noted that the tests carried out with the Panda were carried out some distance from the tests carried out by the BRE using DPH and static cone resistance, which may account for the difference in profiles in the first 2m. The profiles between 2m and 4m are more consistent.

Vale of York

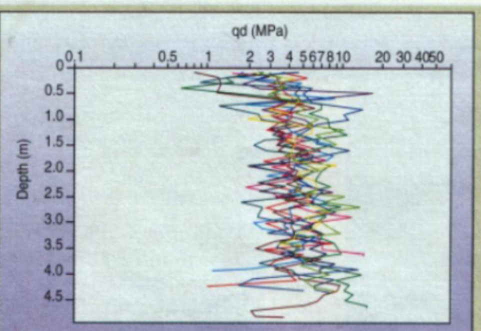


Figure 14: 10 tests carried out in contaminated ground treated using the Colmix process.

Data has also been used for correlation purposes from a location in the Vale of York, which consists of very sandy glacial till with some gravel.

The Panda for ground improvement

The benefit of using the Panda for ground improvement is that it can be used purely as a comparative tool without the need to correlate the data to other parameters. **Figure 14** shows a composite plot using the Panda software of 10 tests carried out in contaminated ground which had been treated by Bachy Soletanche using its Colmix process to prevent contaminants leaching into groundwater. The tests were carried out seven days after the ground had been treated to allow time for the grout to set. A minimum resistance of 1MPa for the treated ground was required and the plot shows the variation in cone resistance across the site after treatment was consistently between 2 and 10MPa.

Summary

Soil type	Typical Panda qd
Very soft clay	0-1MPa
Soft to firm clay	1-2MPa
Firm to stiff clay	2-3MPa
Sand and gravel	4-30MPa

Correlations

The following correlations have been identified as a result of studies carried out in France (Gourves and Barjot 1995), or as a result of a Panda assessment by the Transport Research Laboratory.

1qd = 1MPa (CPT)	(France)
1qd (kPa) = Cu(kPa)/15 to 20	(France)
$\log_{10}CBR = 0.352 + 1.057 \times \log_{10} qd$ (MPa)	(TRL)
TRL mm/blow = 100/qd	(TRL)

Correlations to static cone resistance

The plots of the BRE sites confirm that the Panda gives a good approximation to static cone resistance, as well as confirming that the Panda produces reliable values of cone resistance (qd MPa). **Figure 15** shows Panda data plotted against static cone resistance and includes an X = Y line which fits to data reasonably well.

This relationship has also been recognised by the BRE in stiff clays (Butcher et al, 1995). Establishing a relationship for soft clays, qt = 024 qd +0.14, will require further testing with the Panda.

Correlations to SPT and DCP

The profiles of DCP data converted to cone resistance are very similar to those of static cone resistance and the Panda and hence a good relationship between all the different pieces of apparatus must exist. Correlations between DPH N_{10} and SPT N ($N = 8N_{10} - 6$, Butcher et al, 1995 and $N = 5 \times N_{10}$ AP Butcher, internal BRE report) have already been identified by the BRE for stiff clays. Hence, a correlation from Panda to DPH N_{10} would allow a tentative correlation to SPT to be calculated.

Figure 16 shows values of DPH N_{10} plotted against Panda qd and results in a correlation of $0.8DPH_{10} = 1$ MPa (qd), this gives a correlation of between 0.1 and 0.2 SPT N per 1 MPa (qd). Further direct comparisons between Panda MPa and SPT N values across a range of soil types would help to give confidence and improve this correlation.

Correlations to undrained shear strength

Figure 17 shows data from all the sites visited from horizons where the percentage of clay was greater than 30%, It also includes data from a location in the Vale of York (courtesy of Structural Soils), which consists of very sandy boulder clay with some gravel. The data gives a correlation of Cu (kPa) = qd (kPa)/20. This agrees with the correlation

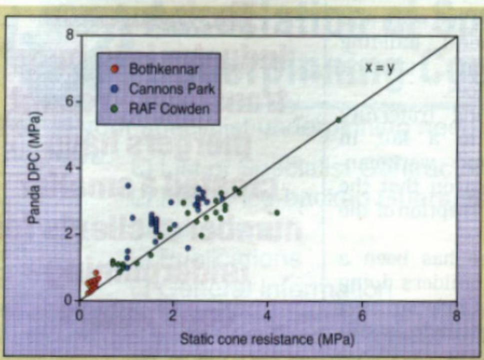


Figure 15: Panda data against static cone resistance.

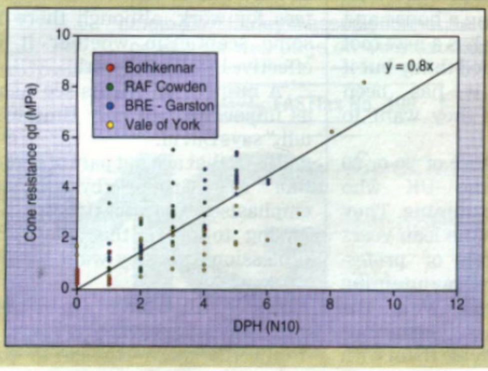


Figure 16: Cone resistance against DPH (N10).

identified in France (Cu = qd/15-20) as well as being similar to the correlation between dynamic cone resistance and undrained shear strength (Cu (kPa) = qd (kPa)/22) identified by the BRE for stiff clays. (Butcher AP, McElmeel K and Powell JJM, 1995).

The BRE has also discovered a second correlation for more sensitive clays, such as very silty clays and very soft clays (cu = (qd/170)+20) which the results from greater than 4m at Pentre appear to follow, however there is insufficient data to verify this correlation at present.

Correlation to TRL DCP and CBR

Figure 18 shows data collected from an assessment of the Panda by the Transport Research Laboratory. The tests were carried out in a series of trenches 900mm deep and backfilled to the surface with type 1 granular sub-base at varying levels of compaction and layer thicknesses. A series of tests were then carried out on each of the trenches with the Panda and the TRL DCP. The data shows a linear relationship with a correlation of TRL mm/blow = 100/qd.

The relationship between penetration in mm/blow can be related to CBR using the TRL Road Note 8 equation and has been adapted for use with the Panda (**Table 3**). Using these two equations, CBR values have been calculated using data collected during the TRL assessment. Values from below 300mm was used as the strength of the material becomes constant below this depth. The values obtained for CBR are comparable with the exception of trench three. Trenches two and three both received comparable levels of compaction and hence similar values of CBR would be expected, such as those obtained from the Panda.

Conclusions

- The results show that the Panda is a lightweight effective tool for testing undisturbed soils up to a depth of 6m and is especially useful where access is restricted.

Table 3: CBR relationships

TRRL Road Note 8 equation $\log_{10}(CBR) = 2.48 - 1.057\log_{10}(mm/blow)$		
Trench 1	Ave mm/blow: 2.6	CBR: 110%
Trench 2	Ave mm/blow: 3.8	CBR: 73%
Trench 3	Ave mm/blow: 2.8	CBR: 100%
Trench 4	Ave mm/blow: 11.8	CBR: 22%
Panda equation $\log_{10} CBR = 0352\ 1.057\log_{10}(MPa)$		
Trench 1	Ave qd: 37	CBR: 102 %
Trench 2	Ave qd: 31	CBR: 84 %
Trench 3	Ave qd: 28	CBR: 76 %
Trench 4	Ave qd: 8	CBR: 20 %

- The Panda has also been used to monitor the compaction of soils and materials in areas of fill, and road pavements. Correlations to the TRL DCP probe and CBR have recently been identified as a result of an assessment by the Transport Research Laboratory, however further trials using a range of materials is needed to establish if these relationships exist in all circumstances.
- The results have also shown that the cone resistance values of the Panda are reliable and show good relationships to other methods of testing.
- Correlations to static cone resistance, dynamic cone resistance, standard penetration test and undrained shear strength already identified by research in France have been verified for the UK.
- Further testing over wider range of different plasticities as well as sands and gravels would clarify these correlations further.
- It must be noted that correlating from one parameter to another reduces the reliability of the value and hence correlations should be kept to a minimum and the values chosen to use in the correlation should be chosen with care. However, with some care and experience good correlations can be made from one parameter to another.

Acknowledgements

The author would like to thank the BRE for allowing the use of its test bed sites and for supplying all the relevant data pertaining to those sites. Special thanks go to John Powell at the BRE. Soil Solution would also like to thank the AMEC/Tarmac joint venture at Manchester Airport, Murray Rix, Structural Soils, Bachy Soletanche and Northumberland County Council for their help.

References

Amor SJ, MH Burtwell and AS Turner (1999). Panda dynamic cone penetrometer assessment. Transport Research Laboratory, Crowthorne.

BS 1377:Part 9:1990 Methods of testing soils for civil engineering purposes. British Standards institution. London.

Butcher AP, McElmeel K & Powell JJM (1995). Dynamic probing and its uses In clay soils, *Proceedings International Conference on Advances in Site Investigation Practice.* ICE London, March 1995. Thomas Telford. pp 383-395.

Butcher AP. The use of dynamic soundings in clays, internal BRE report.

Cassan M (1988). Les essais in situ en méchanique des sols Volume 1 réalisation et interprétation, Eyrolles, 1988, pp 146-151.

Gourves R & Barjot R (1995). The Panda ultralight dynamic penetrometer. Proc 11th Euro. Conf. on Soil Mechanics and Foundation Engineering, 1995 Copenhagen.

Gourves R Panda ultralight dynamic cone penetrometer for soil investigation. Laboratoire de Genie Civil, CUST, Universite Blaise-Pascal de Clermont-Ferrand, France, BP 206 63174 Aubiere.

Jones C R and Rolt J (1991) Information note, Operating instructions for the TRRL dynamic cone penetrometer. Overseas unit information notes, Second edition. Transport Research Laboratory, Crowthorne.

Lunne T, Robertson PK and Powell JJM (1997). CPT in geotechnical practice. Spon.

Marsland A & Powell JJM (1985). Field and laboratory investigations of the clay tills at the Building Research Establishment test site at Cowden Holderness. Proceedings International conference on construction in glacial tills and boulder clays. March 1985 Edinburgh, pp147-168.

Marsland A and Powell, JJM (1989). Field and laboratory investigations of the clay tills at the test bed site at the Building Research Station. Quaternary engineering geology, Geological Society engineering geology special publication No7, pp229-238.

Powell JJM and Quarterman, RST (1995). Engineering geological mapping of soft clay using the piezocone, Proc international symposium on cone penetration testing, CPT'95. Linköping, Sweden, October 1995. Vol 2, pp 263-268

Zhou S (1997) Caracterisation des sols de surface a l'aide du penetrometer dynamic leger a energie variable type Panda. Formation Doctorale "Materiaux, structures, fiabilite en genie civil et genie mecanique" Laboratoire d'Accueil, LERMES/CUST, Universite Blaise Pascal.

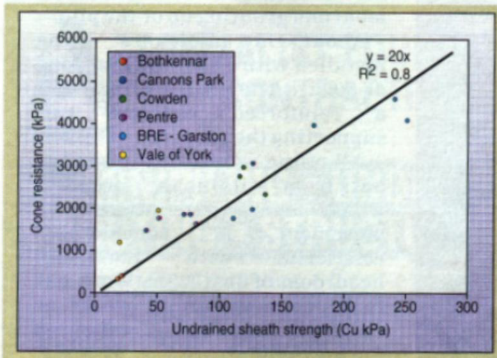


Figure 17: Data from horizons with clay content > 30%

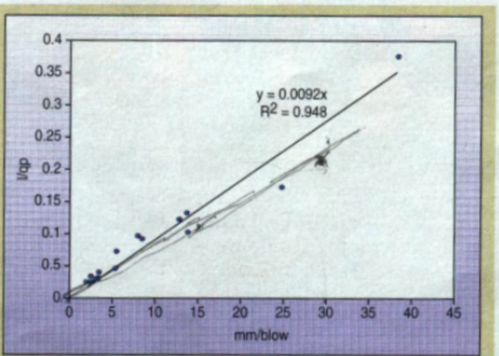


Figure 18: Assessment of Panda by TRL.