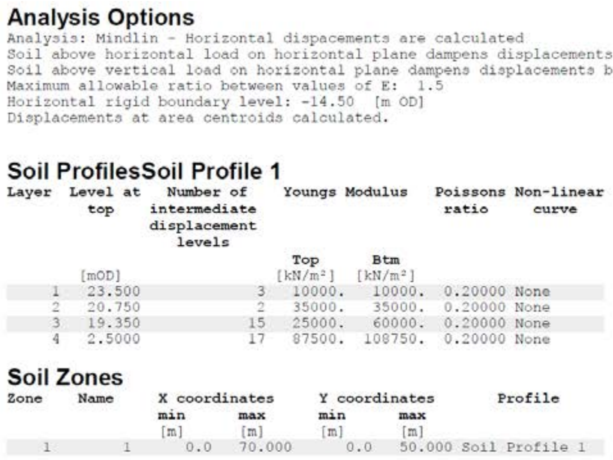
PDISP analysis – input parameters



Analysis Options

```
Analysis: Mindlin - Horizontal dispacements are calculated
Soil above horizontal load on horizontal plane dampens displacements below load : Yes
Soil above vertical load on horizontal plane dampens displacements below load : No
Maximum allowable ratio between values of E:  1.5
Horizontal rigid boundary level: -14.50  [m OD]
Displacements at area centroids calculated.
```

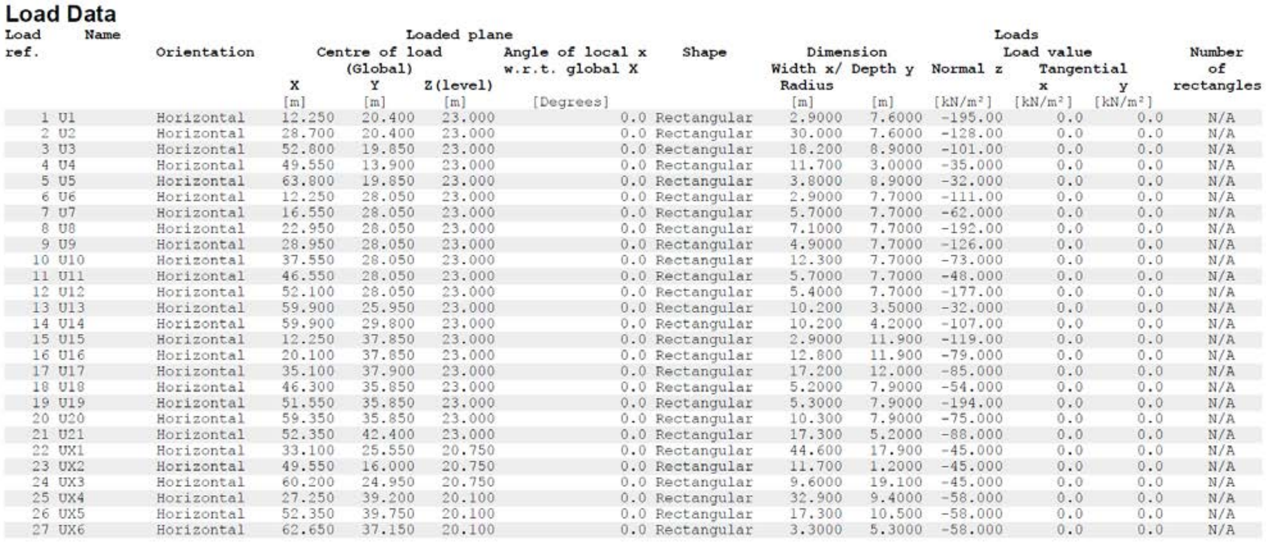
Soil ProfilesSoil Profile 1

Layer	Level at top [mOD]	Number of intermediate displacement levels	Youngs Modulus Top [kN/m²]	Youngs Modulus Btm [kN/m²]	Poissons ratio	Non-linear curve
1	23.500	3	10000.	10000.	0.20000	None
2	20.750	2	35000.	35000.	0.20000	None
3	19.350	15	25000.	60000.	0.20000	None
4	2.5000	17	87500.	108750.	0.20000	None

Soil Zones

Zone	Name	X coordinates min [m]	X coordinates max [m]	Y coordinates min [m]	Y coordinates max [m]	Profile
1	1	0.0	70.000	0.0	50.000	Soil Profile 1

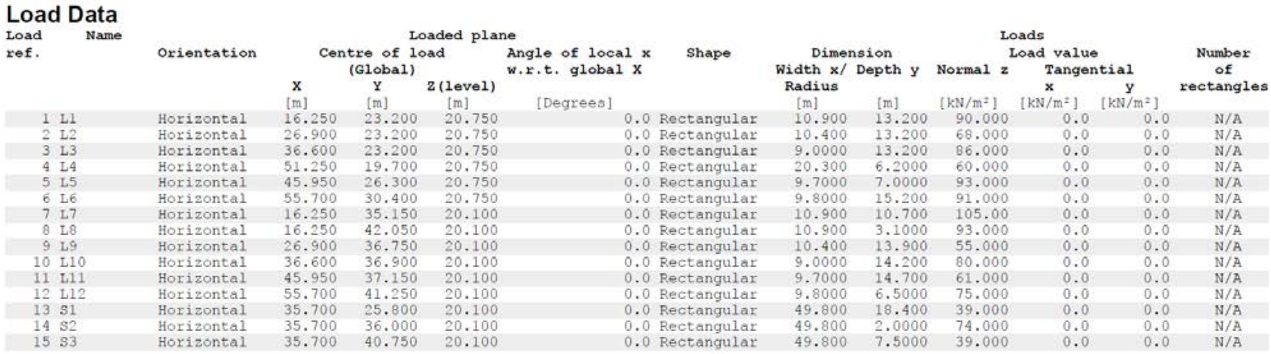
Unload



Load Data

Load ref.	Name	Orientation	Loaded plane Centre of load (Global) X [m]	Y [m]	Z (level) [m]	Angle of local x w.r.t. global X [Degrees]	Shape	Dimension Width x/ Radius [m]	Depth y [m]	Loads Load value Normal z [kN/m²]	Tangential x [kN/m²]	y [kN/m²]	Number of rectangles
1	U1	Horizontal	12.250	20.400	23.000	0.0	Rectangular	2.9000	7.6000	-195.00	0.0	0.0	N/A
2	U2	Horizontal	28.700	20.400	23.000	0.0	Rectangular	30.000	7.6000	-128.00	0.0	0.0	N/A
3	U3	Horizontal	52.800	19.850	23.000	0.0	Rectangular	18.200	8.9000	-101.00	0.0	0.0	N/A
4	U4	Horizontal	49.550	13.900	23.000	0.0	Rectangular	11.700	3.0000	-35.000	0.0	0.0	N/A
5	U5	Horizontal	63.800	19.850	23.000	0.0	Rectangular	3.8000	8.9000	-32.000	0.0	0.0	N/A
6	U6	Horizontal	12.250	28.050	23.000	0.0	Rectangular	2.9000	7.7000	-111.00	0.0	0.0	N/A
7	U7	Horizontal	16.550	28.050	23.000	0.0	Rectangular	5.7000	7.7000	-62.000	0.0	0.0	N/A
8	U8	Horizontal	22.950	28.050	23.000	0.0	Rectangular	7.1000	7.7000	-192.00	0.0	0.0	N/A
9	U9	Horizontal	28.950	28.050	23.000	0.0	Rectangular	4.9000	7.7000	-126.00	0.0	0.0	N/A
10	U10	Horizontal	37.550	28.050	23.000	0.0	Rectangular	12.300	7.7000	-73.000	0.0	0.0	N/A
11	U11	Horizontal	46.550	28.050	23.000	0.0	Rectangular	5.7000	7.7000	-48.000	0.0	0.0	N/A
12	U12	Horizontal	52.100	28.050	23.000	0.0	Rectangular	5.4000	7.7000	-177.00	0.0	0.0	N/A
13	U13	Horizontal	59.900	25.950	23.000	0.0	Rectangular	10.200	3.5000	-32.000	0.0	0.0	N/A
14	U14	Horizontal	59.900	29.800	23.000	0.0	Rectangular	10.200	4.2000	-107.00	0.0	0.0	N/A
15	U15	Horizontal	12.250	37.850	23.000	0.0	Rectangular	2.9000	11.900	-119.00	0.0	0.0	N/A
16	U16	Horizontal	20.100	37.850	23.000	0.0	Rectangular	12.800	11.900	-79.000	0.0	0.0	N/A
17	U17	Horizontal	35.100	37.900	23.000	0.0	Rectangular	17.200	12.000	-85.000	0.0	0.0	N/A
18	U18	Horizontal	46.300	35.850	23.000	0.0	Rectangular	5.2000	7.9000	-54.000	0.0	0.0	N/A
19	U19	Horizontal	51.550	35.850	23.000	0.0	Rectangular	5.3000	7.9000	-194.00	0.0	0.0	N/A
20	U20	Horizontal	59.350	35.850	23.000	0.0	Rectangular	10.300	7.9000	-75.000	0.0	0.0	N/A
21	U21	Horizontal	52.350	42.400	23.000	0.0	Rectangular	17.300	5.2000	-88.000	0.0	0.0	N/A
22	UX1	Horizontal	33.100	25.550	20.750	0.0	Rectangular	44.600	17.900	-45.000	0.0	0.0	N/A
23	UX2	Horizontal	49.550	16.000	20.750	0.0	Rectangular	11.700	1.2000	-45.000	0.0	0.0	N/A
24	UX3	Horizontal	60.200	24.950	20.750	0.0	Rectangular	9.6000	19.100	-45.000	0.0	0.0	N/A
25	UX4	Horizontal	27.250	39.200	20.100	0.0	Rectangular	32.900	9.4000	-58.000	0.0	0.0	N/A
26	UX5	Horizontal	52.350	39.750	20.100	0.0	Rectangular	17.300	10.500	-58.000	0.0	0.0	N/A
27	UX6	Horizontal	62.650	37.150	20.100	0.0	Rectangular	3.3000	5.3000	-58.000	0.0	0.0	N/A

Load



Load Data

Load ref.	Name	Orientation	Loaded plane Centre of load (Global) X [m]	Y [m]	Z (level) [m]	Angle of local x w.r.t. global X [Degrees]	Shape	Dimension Width x/ Radius [m]	Depth y [m]	Loads Load value Normal z [kN/m²]	Tangential x [kN/m²]	y [kN/m²]	Number of rectangles
1	L1	Horizontal	16.250	23.200	20.750	0.0	Rectangular	10.900	13.200	90.000	0.0	0.0	N/A
2	L2	Horizontal	26.900	23.200	20.750	0.0	Rectangular	10.400	13.200	68.000	0.0	0.0	N/A
3	L3	Horizontal	36.600	23.200	20.750	0.0	Rectangular	9.0000	13.200	86.000	0.0	0.0	N/A
4	L4	Horizontal	51.250	19.700	20.750	0.0	Rectangular	20.300	6.2000	60.000	0.0	0.0	N/A
5	L5	Horizontal	45.950	26.300	20.750	0.0	Rectangular	9.7000	7.0000	93.000	0.0	0.0	N/A
6	L6	Horizontal	55.700	30.400	20.750	0.0	Rectangular	9.8000	15.200	91.000	0.0	0.0	N/A
7	L7	Horizontal	16.250	35.150	20.100	0.0	Rectangular	10.900	10.700	105.00	0.0	0.0	N/A
8	L8	Horizontal	16.250	42.050	20.100	0.0	Rectangular	10.900	3.1000	93.000	0.0	0.0	N/A
9	L9	Horizontal	26.900	36.750	20.100	0.0	Rectangular	10.400	13.900	55.000	0.0	0.0	N/A
10	L10	Horizontal	36.600	36.900	20.100	0.0	Rectangular	9.0000	14.200	80.000	0.0	0.0	N/A
11	L11	Horizontal	45.950	37.150	20.100	0.0	Rectangular	9.7000	14.700	61.000	0.0	0.0	N/A
12	L12	Horizontal	55.700	41.250	20.100	0.0	Rectangular	9.8000	6.5000	75.000	0.0	0.0	N/A
13	S1	Horizontal	35.700	25.800	20.100	0.0	Rectangular	49.800	18.400	39.000	0.0	0.0	N/A
14	S2	Horizontal	35.700	36.000	20.100	0.0	Rectangular	49.800	2.0000	74.000	0.0	0.0	N/A
15	S3	Horizontal	35.700	40.750	20.100	0.0	Rectangular	49.800	7.5000	39.000	0.0	0.0	N/A

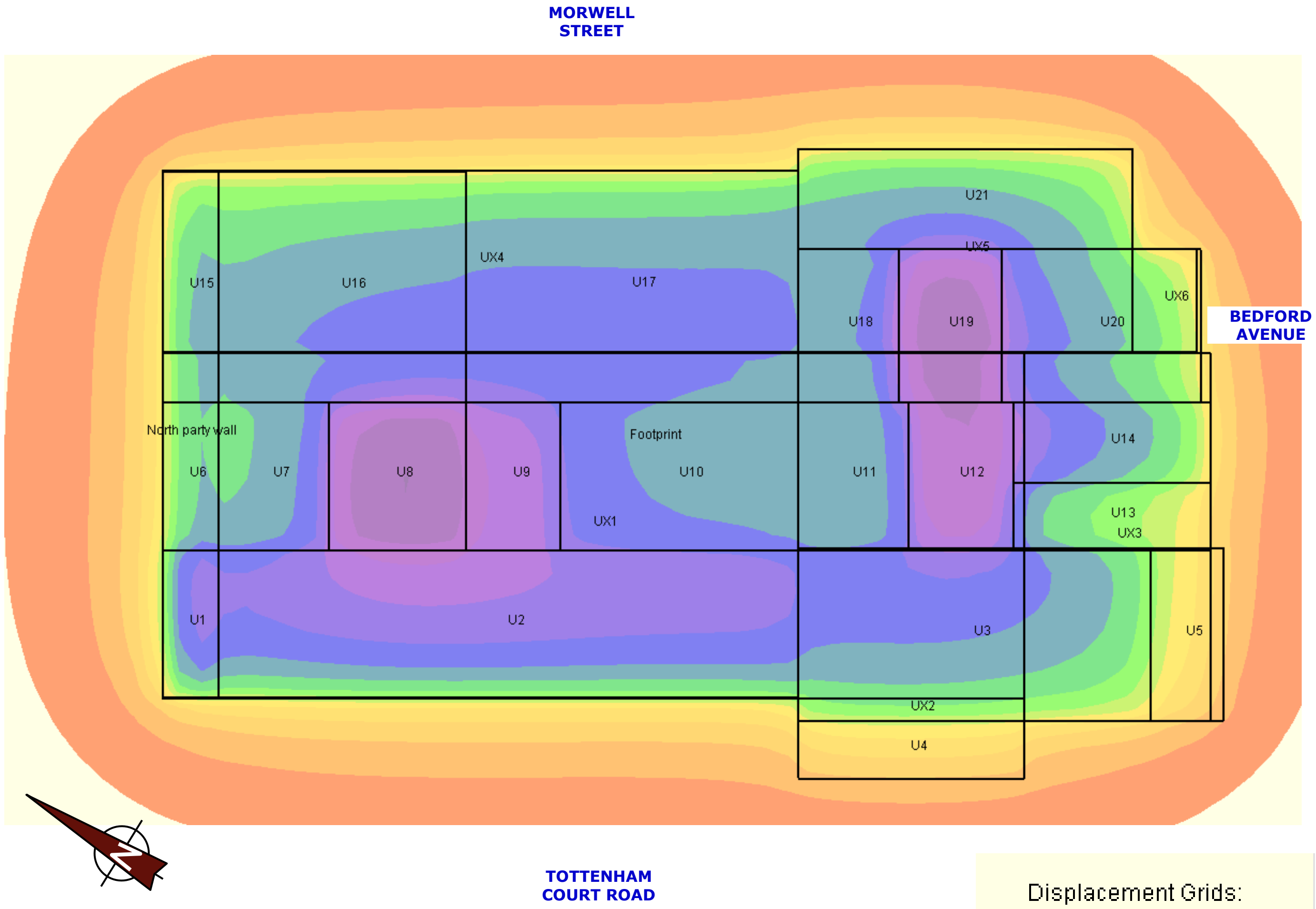
FIGURE 1

Site
Location

One Bedford Avenue
Bedford Avenue, Camden, London WC1B 3AU

Report No:
9661/JRCB

Contours showing short term heave movement during demolition and basement excavation



Displacement Grids:
- ■ < -28 mm
- ■ -28 : -26 mm
- ■ -26 : -24 mm
- ■ -24 : -22 mm
- ■ -22 : -20 mm
- ■ -20 : -18 mm
- ■ -18 : -16 mm
- ■ -16 : -14 mm
- ■ -14 : -12 mm
- ■ -12 : -10 mm
- ■ -10 : -8 mm
- ■ -8 : -6 mm
- ■ -6 : -4 mm
- ■ -4 : -2 mm
- ■ -2 : 0 mm
- ▭ Displacement Lines

Notes:

a] contours show the short term heave movement during demolition and basement excavatio

b] contours show ground movement at basement excavation level [+20.1mOD]

c] negative movement is upward [heave], positive movement is downward [settlement]

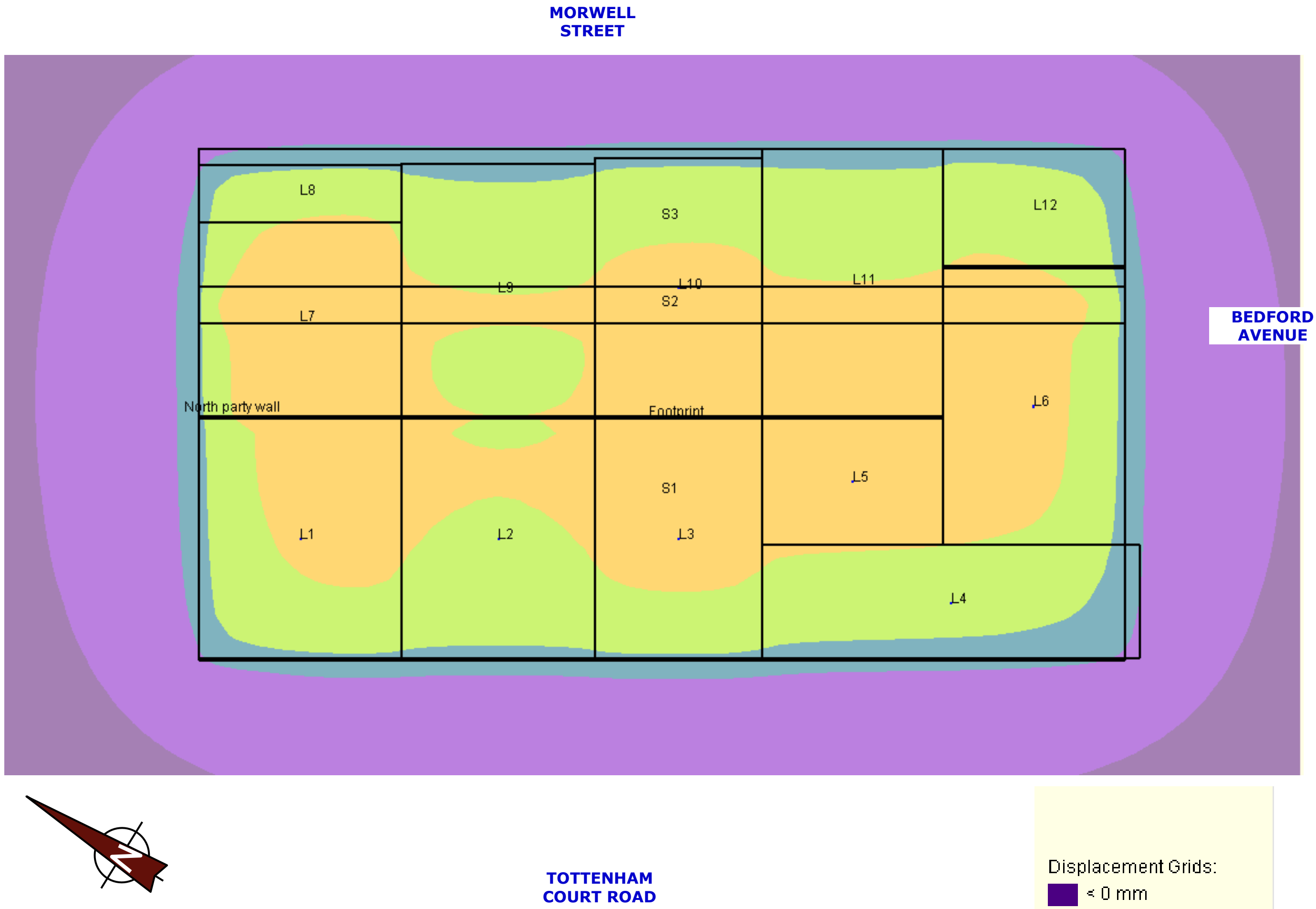
FIGURE 2

Site Location

One Bedford Avenue
Bedford Avenue, Camden, London WC1B 3AU

Report No:
9661/JRCB

Contours showing settlement during construction



Displacement Grids:
🟪 < 0 mm
🟪 0 : 5 mm
🟦 5 : 10 mm
🟩 10 : 15 mm
🟧 15 : 20 mm
🟥 > 20 mm
▭ Displacement Lines

Notes:

a] contours show immediate settlement

b] contours show ground movement at basement excavation level [+20.1mOD]

c] negative movement is upward [heave], positive movement is downward [settlement]

d] the contours show predicted ground movement for fully flexible conditions. A ‘rigidity’ factor should be applied to the calculated settlements to take account of raft stiffness [see report text]

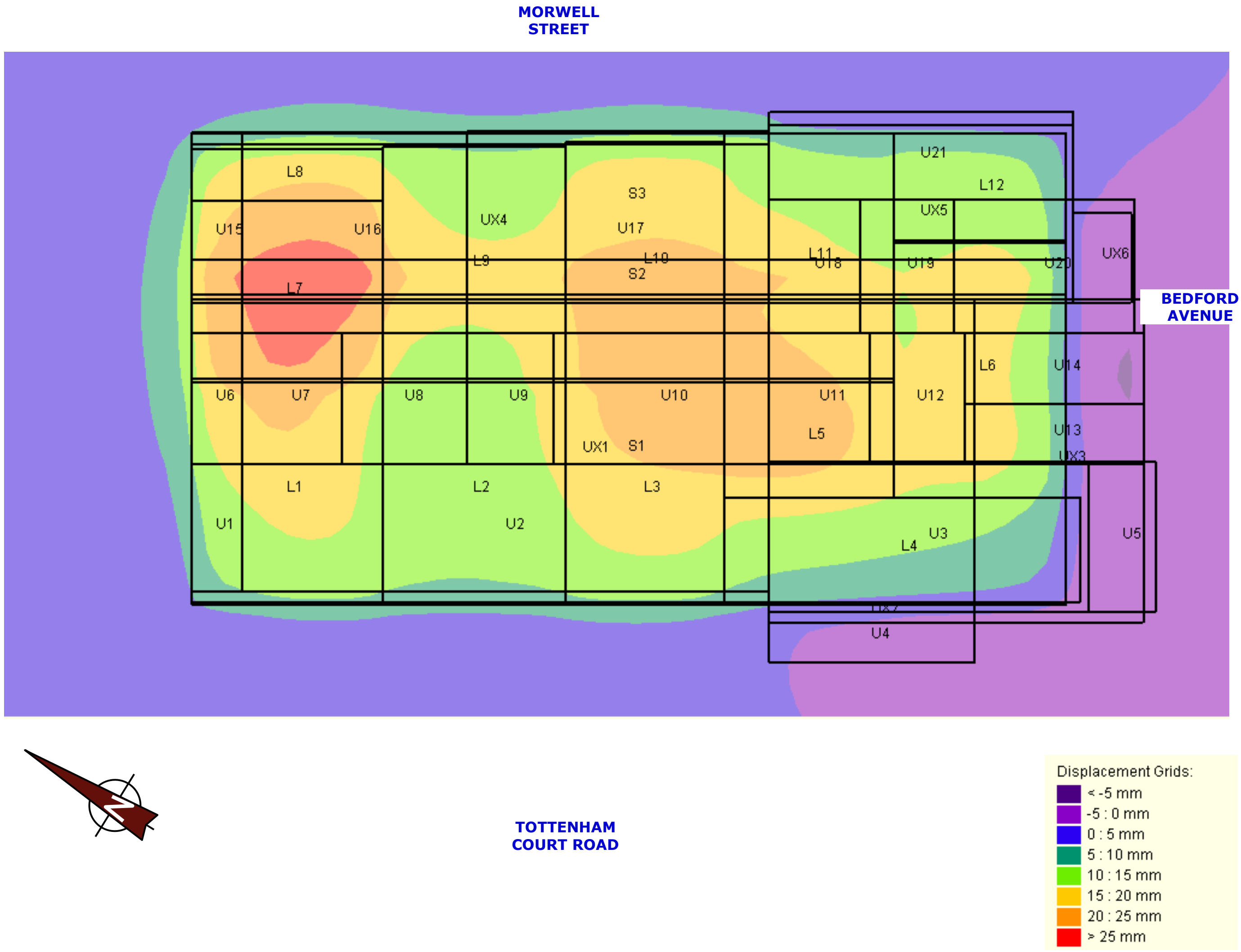
FIGURE 3

Site Location

One Bedford Avenue
Bedford Avenue, Camden, London WC1B 3AU

Report No:
9661/JRCB

Contours showing total long term settlement (including immediate)



Notes:

a] contours show total long term movement [taking into account net loading]

b] contours show ground movement at basement excavation level [+20.1mOD]

c] negative movement is upward [heave], positive movement is downward [settlement]

d] the contours show predicted ground movement for fully flexible conditions. A 'rigidity' factor should be applied to the calculated settlements to take account of raft stiffness [see report text]

FIGURE 4

Predicted movement at the Northern party wall

RESULTS FOR GRIDS

Analysis: Mindlin
Maximum allowable ratio between values of E: 1.5
Horizontal rigid boundary level: -14.50 [m OD]

Unload – short term

Name	Location			Displacement		
	X [m]	Y [m]	Z[Level] [mOD]	X [mm]	Y [mm]	Z [mm]
North party wall	10.00000	16.60000	20.10000	-26.988	-18.828	-3.9046
	10.00000	19.32000	20.10000	-31.506	-14.868	-6.5127
	10.00000	22.04000	20.10000	-33.694	-10.015	-7.2633
	10.00000	24.76000	20.10000	-34.007	-5.4759	-6.8067
	10.00000	27.48000	20.10000	-33.936	-2.1104	-6.3627
	10.00000	30.20000	20.10000	-33.871	1.1427	-6.2163
	10.00000	32.92000	20.10000	-33.678	4.3976	-6.1704
	10.00000	35.64000	20.10000	-33.402	7.9826	-6.0155
	10.00000	38.36000	20.10000	-32.060	11.900	-5.6172
	10.00000	41.08000	20.10000	-29.623	15.657	-4.7619
	10.00000	43.80000	20.10000	-25.417	18.758	-2.7499

Load – short term

North party wall	10.00000	16.60000	20.10000	17.932	13.790	2.4994
	10.00000	19.32000	20.10000	20.548	11.933	4.2614
	10.00000	22.04000	20.10000	22.421	9.4760	5.0279
	10.00000	24.76000	20.10000	23.779	6.9250	5.4259
	10.00000	27.48000	20.10000	24.882	4.4342	5.6483
	10.00000	30.20000	20.10000	26.379	1.8462	5.7314
	10.00000	32.92000	20.10000	27.170	-1.7245	5.7682
	10.00000	35.64000	20.10000	27.042	-5.4009	5.8031
	10.00000	38.36000	20.10000	25.634	-9.1232	5.2247
	10.00000	41.08000	20.10000	23.317	-12.321	4.2401
	10.00000	43.80000	20.10000	19.750	-14.732	2.4906

Load – net long term

North party wall	10.00000	16.60000	20.10000	3.4781	4.6780	2.4159
	10.00000	19.32000	20.10000	5.5791	4.0639	3.8520
	10.00000	22.04000	20.10000	6.6330	3.1769	4.9304
	10.00000	24.76000	20.10000	7.0818	2.6682	6.4055
	10.00000	27.48000	20.10000	7.5995	2.6577	7.7202
	10.00000	30.20000	20.10000	8.9499	2.4935	8.7024
	10.00000	32.92000	20.10000	9.8604	1.1520	9.2524
	10.00000	35.64000	20.10000	9.8791	-0.35278	9.5073
	10.00000	38.36000	20.10000	9.0521	-1.9299	8.5335
	10.00000	41.08000	20.10000	7.6091	-3.3690	7.0403
	10.00000	43.80000	20.10000	5.0638	-4.4276	4.7512

FIGURE 5

Predicted short term movement at the Eastern tunnel centreline [unload]

RESULTS FOR GRIDS

Analysis: Mindlin
Maximum allowable ratio between values of E: 1.5
Horizontal rigid boundary level: -14.50 [m OD]

Name	Location			Displacement		
	X [m]	Y [m]	Z[Level] [mOD]	X [mm]	Y [mm]	Z [mm]
East tunnel CL	.00000	10.60000	-1.90000	3.9152	2.4717	-0.30949
	2.80000	10.62400	-1.90000	4.0124	2.7969	-0.44422
	5.60000	10.64800	-1.90000	4.0489	3.1456	-0.59915
	8.40000	10.67200	-1.90000	4.0106	3.5092	-0.76888
	11.20000	10.69600	-1.90000	3.8877	3.8763	-0.94544
	14.00000	10.72000	-1.90000	3.6776	4.2335	-1.1193
	16.80000	10.74400	-1.90000	3.3850	4.5679	-1.2814
	19.60000	10.76800	-1.90000	3.0209	4.8683	-1.4244
	22.40000	10.79200	-1.90000	2.6001	5.1264	-1.5441
	25.20000	10.81600	-1.90000	2.1384	5.3374	-1.6389
	28.00000	10.84000	-1.90000	1.6501	5.4994	-1.7098
	30.80000	10.86400	-1.90000	1.1468	5.6127	-1.7591
	33.60000	10.88800	-1.90000	0.63632	5.6795	-1.7897
	36.40000	10.91200	-1.90000	0.12340	5.7017	-1.8040
	39.20000	10.93600	-1.90000	-0.38977	5.6813	-1.8034
	42.00000	10.96000	-1.90000	-0.90172	5.6188	-1.7874
	44.80000	10.98400	-1.90000	-1.4099	5.5138	-1.7539
	47.60000	11.00800	-1.90000	-1.9089	5.3652	-1.6997
	50.40000	11.03200	-1.90000	-2.3893	5.1719	-1.6213
	53.20000	11.05600	-1.90000	-2.8377	4.9342	-1.5166
	56.00000	11.08000	-1.90000	-3.2380	4.6547	-1.3857
	58.80000	11.10400	-1.90000	-3.5737	4.3393	-1.2318
	61.60000	11.12800	-1.90000	-3.8313	3.9969	-1.0613
	64.40000	11.15200	-1.90000	-4.0026	3.6390	-0.88288
	67.20000	11.17600	-1.90000	-4.0865	3.2782	-0.70640
	70.00000	11.20000	-1.90000	-4.0895	2.9262	-0.54075

FIGURE 6

Theoretical unconstrained total heave at the Eastern tunnel centreline

RESULTS FOR GRIDS

Analysis: Mindlin
Maximum allowable ratio between values of E: 1.5
Horizontal rigid boundary level: -14.50 [m OD]

Name	Location X [m]	Location Y [m]	Location Z[Level] [mOD]	Displacement X [mm]	Displacement Y [mm]	Displacement Z [mm]
East tunnel CL	.00000	10.60000	-1.90000	0.84859	0.66845	-1.4282
	2.80000	10.62400	-1.90000	0.98095	0.84184	-1.7309
	5.60000	10.64800	-1.90000	1.0845	1.0303	-2.0655
	8.40000	10.67200	-1.90000	1.1507	1.2289	-2.4220
	11.20000	10.69600	-1.90000	1.1737	1.4308	-2.7873
	14.00000	10.72000	-1.90000	1.1515	1.6285	-3.1459
	16.80000	10.74400	-1.90000	1.0866	1.8144	-3.4830
	19.60000	10.76800	-1.90000	0.98488	1.9821	-3.7858
	22.40000	10.79200	-1.90000	0.85456	2.1266	-4.0461
	25.20000	10.81600	-1.90000	0.70439	2.2450	-4.2591
	28.00000	10.84000	-1.90000	0.54226	2.3364	-4.4243
	30.80000	10.86400	-1.90000	0.37422	2.4007	-4.5434
	33.60000	10.88800	-1.90000	0.20416	2.4391	-4.6193
	36.40000	10.91200	-1.90000	0.033873	2.4529	-4.6547
	39.20000	10.93600	-1.90000	-0.13626	2.4428	-4.6509
	42.00000	10.96000	-1.90000	-0.30630	2.4094	-4.6076
	44.80000	10.98400	-1.90000	-0.47562	2.3524	-4.5223
	47.60000	11.00800	-1.90000	-0.64194	2.2709	-4.3916
	50.40000	11.03200	-1.90000	-0.80053	2.1646	-4.2123
	53.20000	11.05600	-1.90000	-0.94434	2.0336	-3.9830
	56.00000	11.08000	-1.90000	-1.0646	1.8794	-3.7056
	58.80000	11.10400	-1.90000	-1.1524	1.7055	-3.3866
	61.60000	11.12800	-1.90000	-1.1998	1.5169	-3.0366
	64.40000	11.15200	-1.90000	-1.2024	1.3203	-2.6701
	67.20000	11.17600	-1.90000	-1.1594	1.1230	-2.3027
	70.00000	11.20000	-1.90000	-1.0749	0.93197	-1.9497

FIGURE 7

Predicted short term movement at the Eastern tunnel centreline [load]

RESULTS FOR GRIDS

```
Analysis: Mindlin
Maximum allowable ratio between values of E:  1.5
Horizontal rigid boundary level: -14.50  [m OD]

   Name                   Location                       Displacement
                     X          Y       Z[Level]       X          Y          Z
                    [m]        [m]       [mOD]       [mm]       [mm]       [mm]

East tunnel CL     .00000   10.60000  -1.90000     -2.8486    -1.9397    0.23047
                  1.40000   10.61200  -1.90000     -2.8816    -2.0613    0.27711
                  2.80000   10.62400  -1.90000     -2.9043    -2.1875    0.32753
                  4.20000   10.63600  -1.90000     -2.9154    -2.3177    0.38139
                  5.60000   10.64800  -1.90000     -2.9136    -2.4510    0.43829
                  7.00000   10.66000  -1.90000     -2.8976    -2.5866    0.49765
                  8.40000   10.67200  -1.90000     -2.8665    -2.7234    0.55876
                  9.80000   10.68400  -1.90000     -2.8198    -2.8601    0.62089
                 11.20000   10.69600  -1.90000     -2.7571    -2.9955    0.68315
                 12.60000   10.70800  -1.90000     -2.6783    -3.1285    0.74472
                 14.00000   10.72000  -1.90000     -2.5840    -3.2578    0.80473
                 15.40000   10.73200  -1.90000     -2.4749    -3.3822    0.86245
                 16.80000   10.74400  -1.90000     -2.3519    -3.5008    0.91721
                 18.20000   10.75600  -1.90000     -2.2162    -3.6127    0.96847
                 19.60000   10.76800  -1.90000     -2.0692    -3.7171     1.0158
                 21.00000   10.78000  -1.90000     -1.9123    -3.8134     1.0590
                 22.40000   10.79200  -1.90000     -1.7468    -3.9014     1.0980
                 23.80000   10.80400  -1.90000     -1.5740    -3.9807     1.1326
                 25.20000   10.81600  -1.90000     -1.3950    -4.0510     1.1630
                 26.60000   10.82800  -1.90000     -1.2110    -4.1124     1.1893
                 28.00000   10.84000  -1.90000     -1.0228    -4.1648     1.2115
                 29.40000   10.85200  -1.90000    -0.83113    -4.2081     1.2298
                 30.80000   10.86400  -1.90000    -0.63677    -4.2423     1.2443
                 32.20000   10.87600  -1.90000    -0.44032    -4.2675     1.2551
                 33.60000   10.88800  -1.90000    -0.24240    -4.2836     1.2622
                 35.00000   10.90000  -1.90000   -0.043554    -4.2906     1.2656
                 36.40000   10.91200  -1.90000     0.15564    -4.2884     1.2653
                 37.80000   10.92400  -1.90000     0.35459    -4.2770     1.2613
                 39.20000   10.93600  -1.90000     0.55264    -4.2564     1.2535
                 40.60000   10.94800  -1.90000     0.74910    -4.2266     1.2418
                 42.00000   10.96000  -1.90000     0.94326    -4.1874     1.2262
                 43.40000   10.97200  -1.90000      1.1343    -4.1390     1.2066
                 44.80000   10.98400  -1.90000      1.3214    -4.0813     1.1829
                 46.20000   10.99600  -1.90000      1.5036    -4.0145     1.1549
                 47.60000   11.00800  -1.90000      1.6799    -3.9387     1.1228
                 49.00000   11.02000  -1.90000      1.8491    -3.8541     1.0865
                 50.40000   11.03200  -1.90000      2.0102    -3.7610     1.0460
                 51.80000   11.04400  -1.90000      2.1619    -3.6598     1.0014
                 53.20000   11.05600  -1.90000      2.3029    -3.5510    0.95306
                 54.60000   11.06800  -1.90000      2.4322    -3.4354    0.90112
                 56.00000   11.08000  -1.90000      2.5484    -3.3137    0.84609
                 57.40000   11.09200  -1.90000      2.6507    -3.1867    0.78846
                 58.80000   11.10400  -1.90000      2.7383    -3.0556    0.72889
                 60.20000   11.11600  -1.90000      2.8105    -2.9215    0.66807
                 61.60000   11.12800  -1.90000      2.8671    -2.7855    0.60681
                 63.00000   11.14000  -1.90000      2.9081    -2.6488    0.54586
                 64.40000   11.15200  -1.90000      2.9340    -2.5126    0.48601
                 65.80000   11.16400  -1.90000      2.9453    -2.3780    0.42797
                 67.20000   11.17600  -1.90000      2.9431    -2.2459    0.37239
                 68.60000   11.18800  -1.90000      2.9284    -2.1173    0.31978
                 70.00000   11.20000  -1.90000      2.9026    -1.9929    0.27054
```

FIGURE 8

Predicted net long term movement at the Eastern tunnel centreline

RESULTS FOR GRIDS

Analysis: Mindlin
Maximum allowable ratio between values of E: 1.5
Horizontal rigid boundary level: -14.50 [m OD]

Name	Location			Displacement		
	X	Y	Z[Level]	X	Y	Z
	[m]	[m]	[mOD]	[mm]	[mm]	[mm]
East tunnel CL	.00000	10.60000	-1.90000	-0.10904	-0.18122	0.30182
	1.40000	10.61200	-1.90000	-0.13893	-0.21982	0.33898
	2.80000	10.62400	-1.90000	-0.16653	-0.26086	0.37894
	4.20000	10.63600	-1.90000	-0.19121	-0.30381	0.42116
	5.60000	10.64800	-1.90000	-0.21232	-0.34847	0.46558
	7.00000	10.66000	-1.90000	-0.22936	-0.39430	0.51155
	8.40000	10.67200	-1.90000	-0.24185	-0.44085	0.55855
	9.80000	10.68400	-1.90000	-0.24958	-0.48746	0.60597
	11.20000	10.69600	-1.90000	-0.25240	-0.53348	0.65300
	12.60000	10.70800	-1.90000	-0.25041	-0.57838	0.69910
	14.00000	10.72000	-1.90000	-0.24392	-0.62160	0.74346
	15.40000	10.73200	-1.90000	-0.23338	-0.66260	0.78557
	16.80000	10.74400	-1.90000	-0.21928	-0.70103	0.82496
	18.20000	10.75600	-1.90000	-0.20235	-0.73651	0.86126
	19.60000	10.76800	-1.90000	-0.18310	-0.76892	0.89426
	21.00000	10.78000	-1.90000	-0.16218	-0.79821	0.92378
	22.40000	10.79200	-1.90000	-0.14007	-0.82436	0.94993
	23.80000	10.80400	-1.90000	-0.11704	-0.84735	0.97264
	25.20000	10.81600	-1.90000	-0.093349	-0.86735	0.99208
	26.60000	10.82800	-1.90000	-0.069103	-0.88440	1.0083
	28.00000	10.84000	-1.90000	-0.044268	-0.89862	1.0214
	29.40000	10.85200	-1.90000	-0.018827	-0.90990	1.0313
	30.80000	10.86400	-1.90000	0.0073385	-0.91827	1.0381
	32.20000	10.87600	-1.90000	0.034222	-0.92361	1.0415
	33.60000	10.88800	-1.90000	0.061811	-0.92582	1.0416
	35.00000	10.90000	-1.90000	0.089945	-0.92471	1.0380
	36.40000	10.91200	-1.90000	0.11850	-0.92014	1.0308
	37.80000	10.92400	-1.90000	0.14715	-0.91186	1.0197
	39.20000	10.93600	-1.90000	0.17550	-0.89984	1.0047
	40.60000	10.94800	-1.90000	0.20306	-0.88394	0.98568
	42.00000	10.96000	-1.90000	0.22948	-0.86407	0.96266
	43.40000	10.97200	-1.90000	0.25421	-0.84023	0.93575
	44.80000	10.98400	-1.90000	0.27674	-0.81240	0.90503
	46.20000	10.99600	-1.90000	0.29664	-0.78078	0.87071
	47.60000	11.00800	-1.90000	0.31333	-0.74539	0.83297
	49.00000	11.02000	-1.90000	0.32652	-0.70654	0.79209
	50.40000	11.03200	-1.90000	0.33569	-0.66443	0.74843
	51.80000	11.04400	-1.90000	0.34049	-0.61953	0.70228
	53.20000	11.05600	-1.90000	0.34053	-0.57213	0.65418
	54.60000	11.06800	-1.90000	0.33548	-0.52280	0.60458
	56.00000	11.08000	-1.90000	0.32522	-0.47206	0.55403
	57.40000	11.09200	-1.90000	0.30954	-0.42056	0.50315
	58.80000	11.10400	-1.90000	0.28849	-0.36887	0.45263
	60.20000	11.11600	-1.90000	0.26232	-0.31780	0.40316
	61.60000	11.12800	-1.90000	0.23134	-0.26791	0.35540
	63.00000	11.14000	-1.90000	0.19614	-0.21993	0.30997
	64.40000	11.15200	-1.90000	0.15746	-0.17425	0.26734
	65.80000	11.16400	-1.90000	0.11601	-0.13148	0.22799
	67.20000	11.17600	-1.90000	0.072726	-0.091827	0.19217
	68.60000	11.18800	-1.90000	0.028440	-0.055634	0.16002
	70.00000	11.20000	-1.90000	-0.016002	-0.022881	0.13156

FIGURE 9

APPENDIX C

Pressuremeter report (details TBC)

One Bedford Avenue,
Camden, London, WC1

GROUND INVESTIGATION

Results of self bored pressuremeter testing carried out by Cambridge Insitu, September 2014

Our reference:	**CIR1312/14**
Main Contractor's ref:	
Original report date:	**Jan 2015**
Version:	**1.0**

Volume 1 of 1

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VOLUME 1 TEXT REPORT AND RESULTS SUMMARY

APPENDICES

One Bedford Avenue, Ground Investigation

1 Introduction

Cambridge Insitu Ltd (CI) was contracted by Soil Consultants Ltd (the Contractor) to carry out Self Boring Pressuremeter (SBP) testing at a single location on the perimeter of One Bedford Avenue. The purpose of the testing was to produce representative parameters for the stiffness, strength and insitu lateral stress of the ground. The SBP is able to provide *insitu* stiffness data with a high reliability, and strength together with an estimate of the initial state of stress in the ground to a slightly greater uncertainty. The field work took place between the 15th and 17th of September 2014, and Soil Consultants instructed the testing.

Four successful tests were carried out at depths between 9 and 25 metres below ground level. The first three tests were in London Clay, the final test was in the mottled clay of the Lambeth Group.

The SBP (known as ‘Dougal’) was driven using a proprietary drilling system that couples to a length of water well casing. See Appendix A for further details. Provided the casing is firmly placed the friction acting on it allows jacking force to be supplied for the self boring process. A cable percussion rig stood over the borehole and removed material between pressuremeter test points, so the SBP self bored for only four metres in total.

This report is concerned solely with the presentation of the SBP test results.

1.1 Instrument

The Self-boring Pressuremeter and method was invented and developed at Cambridge University by Hughes and Wroth during the 1970’s. It is a two phase process. The device is first bored into the ground in a controlled manner that results in only minor alteration of the *insitu* stress condition of the soil mass. Once in place, gas pressure is applied down an umbilical hose/cable to the inner surface of an elastic membrane covering approximately half of the instrument length. This pressure causes the membrane to load the borehole wall and carry out a cavity expansion test. Clays and sands are most suited to this method of pressuremeter testing, materials difficult to sample without major disruption to their natural stress state.

Three equally-spaced displacement transducers track the movement of the inside of the membrane while an internal pressure transducer measures the applied pressure. The SBP is also equipped with two opposite facing pore water pressure measuring transducers positioned at the midpoint of the membrane. These allow the pore water pressure regime to be monitored throughout the drilling and testing phases.

The instrument also contains all the necessary signal conditioning electronics so that a digitally encoded RS232 data stream can be sent to the surface ready for direct connection to the USB port of a personal computer. Further detailed information on the instrument, drilling process and testing procedure can be found in the appendices of this report.

1.2 Analysis

The pressuremeter loading curve can be solved directly using mathematical expressions for the expansion of a cylindrical cavity. The solution is conventionally quoted in terms of stiffness and strength parameters for the material, specifically shear modulus, shear strength or friction angle as appropriate, and the insitu lateral stress. This fundamental approach is not the only way to interpret pressuremeter data, but is common practice in the UK. The success of this method is dependent on the validity of the assumptions that have to be made:

- In terms of the soil response, it is assumed that the material is fully saturated, homogenous, isotropic and behaving as a continuum that fails in shear only.
- It is assumed that the length to diameter ratio of the expanding section be large enough for end effects to be negligible, allowing for the test to be modelled as a plane strain expansion.
- The pressuremeter test gives data for the total radial stress and radial displacements of the cavity wall. The displacements are directly related to the hoop strain. However in order to solve the boundary problem represented by a cavity expansion the radial strain and circumferential stress must also be known. If it is assumed that the test is undrained (as it would be for most clays) then the loading takes place without generating volumetric strains. This means that radial and shear strains are derived easily from circumferential strain.
- In addition it is assumed that the cavity expands as a circle and hence the results have been obtained by analysing the curve derived from the average of all displacement followers as this gives the best representation of a circular expansion. The pressuremeter expands in an approximately circular manner, even if the resulting circle is offset to one side. Cavity expansion theory demands a circular expansion, so a plot of average displacement versus applied pressure is used in the analysis procedure.

For this contract the tests have been analysed as undrained expansions using the closed form solution proposed by Bolton & Whittle (1999). This assumes a non linear elastic/perfectly plastic shear stress:shear strain response and can provide good data for the undrained shear strength (c_u) and limit pressure (p_{lim}).

We make use of the pressuremeter final unloading curve and the solution proposed by Jefferies (1988) allows the undrained strength to be determined.

Modulus data are obtained from the local slope of parts of the pressure/strain test curve. The conventional values quoted are derived from the slope of the initial loading and of the chord bisecting cycles of unloading and reloading. The initial slope is likely to be influenced by disturbance due to the process of getting the pressuremeter into the ground - unload/reload cycles avoid this problem and are able to give consistent and repeatable descriptions of stiffness characteristics. In soils these cycles appear hysteretic and this non-linearity allows the degradation of stiffness with increasing strain to be described.

Pressuremeters shear the material and so the modulus obtained is shear modulus G. If Young's modulus E is required then provided the material is isotropic the relationship $E = 2G(1+\mu)$ can be used where μ is Poisson's ratio. Shear modulus from a horizontally oriented cavity expansion is G_{hh}, and should be adjusted appropriately when used to calculate vertically influenced deformation.

Modulus parameters are also stress dependent, and estimates of the insitu lateral stress characteristics of the material have been provided to allow this dependency to be normalised. Lateral stress estimates can be obtained by direct observation but in general are better recovered through a curve matching process, where the analysed results are combined to see if they reproduce the measured field curve. The major uncertainty in this procedure is the insitu lateral stress and a straightforward optimisation process is used to identify the most plausible value.

If the overburden and likely pore water profile are known then the values for lateral stress can be used to give estimates of the co-efficient of earth pressure at rest, k_o.

Additional parameters or correlations such as the over consolidation ratio and inferred angle of internal friction can be derived and are quoted, but these are not measured directly by the pressuremeter.

1.3 Report

Although it is necessary to make judgments when analysing the data, this remains a factual report. The parameters derived represent what seems a reasonable choice having applied a particular analysis. Other choices are possible and the intention is that this report provides a full description of the tests and analytical methods employed so that the choices made here can be checked or modified.

Part three of this volume contains tables of all the results with some figures showing parameters plotted against depth. The depth used is metres below basement level, the measurement made in the field.

Appendix D is a guide to the analyses that have been applied, and uses examples from the tests on this contract to show how choices are made and the implications.

The test data are` also available as files of readings in engineering units in a format easily accessed by several common spreadsheet programs.

1.4 Notation

The data collection system employed on site utilises a limited keyboard that restricts the options for describing a test. In particular it stores tests in the form B**** T** where **** must be a number. The ‘B’, which may be modified, is intended to refer to the borehole and the ‘T’ refers to the individual test, so a typical test reference used here is B1T3 – the third test in borehole BH1.

Calibration tests to evaluate membrane stiffness and system compliance are reported in a similar manner, but using a test number that cannot be confused with an actual test.

1.5 Units

Pressure is quoted throughout in Pascals. The smallest unit of pressure quoted is 1 kPa. Displacements are quoted in millimetres; once an estimate of the insitu lateral stress has been made, hence allowing the original cavity diameter to be inferred, then these are converted to percent cavity strain.

1.6 Personnel

The field work was carried out by Simon Baxter and James Dalton of CI. Robert Whittle of CI prepared this report.

1.7 Headers and footers

The header used on every page of this text report refers to the contract and the approximate date of the field work. The footer (intended for CI internal use only) refers to the document name and version number.

2. Details of the work carried out

Table 2.1 The tests

Test	Internal reference	Depth	Date	Test Method	Operator	Max Press.	Material
BH1		**(mBGL)**				**(kPa)**	
Test 1	B01T1	9.80	15-Sep-14	Self bored	SDB/JAHD	908	London Clay
Test 2	B01T2	15.30	15-Sep-14	Self bored	SDB/JAHD	1388	London Clay
Test 3	B01T3	20.00	16-Sep-14	Self bored	SDB/JAHD	1401	London Clay
Test 4	B01T4	25.00	17-Sep-14	Self bored	SDB/JAHD	1921	Lambeth Group (clay)

Table 2.2 Calibration details

Probe type	Probe reference	Transducer calibration	Stiffness calibration	Compliance calibration	Straightness Check
3 Arm SBP	Dougal	11/08/2014	Z0204T14	Z0204T15	01/04/2014

Table 2.3 Test notes

Test	Depth	Remarks
BH1	**(mBGL)**	
Test 1	9.80	PPC show a zero shift, thought to be caused by poor de-airing. Cells working o.k.
Test 2	15.30	PPCs o.k.
Test 3	20.00	Lost flush to hole for most of drilling. Had to stop drilling to wait for water. Bottom partially blocked off. PPC zero shift but working o.k.
Test 4	25.00	PPC A zero shift.

Notes:

1. Test depth is given as metres below ground level. The measure is to the centre of the expanding portion. The pressuremeter membrane is 0.46 metres long for the SBP. The zone affected by the test is therefore ± 0.23m of the quoted test centre.
2. ‘Max Press’ refers to the maximum pressure achieved during each test.
3. Two operators from Cambridge Insitu ran the pressuremeter testing, Simon Baxter (SDB) and James Dalton (JAHD).

3. Summary of Results

Table 3.1 Initial stress state -

Test	Date	Depth	Origin	u_o	σ_{ho}	σ_{vo}	k_o	OCR
BH1		(mBGL)	(mm)	(kPa)	(kPa)	(kPa)		
Test 1	15-Sep-14	9.80	0.48	47	219	196	1.15	4.9
Test 2	15-Sep-14	15.30	0.67	101	282	306	0.88	7.6
Test 3	16-Sep-14	20.00	0.75	147	469	400	1.27	4.7
Test 4	17-Sep-14	25.00	0.15	196	588	500	1.29	5.2

Notes on table 3.1

1. **Depth** is the distance below ground) level to the centre of the pressuremeter measuring section.
2. **Origin** is the offset required to restore insitu conditions at the cavity wall. If the figure is negative then the test section has been ‘pushed’ during self boring. If positive then the material has been stress relieved during self boring.
3. $\mathbf{u_o}$ is the ambient pore water pressure, assuming a water table at 5 metres below basement level.
4. $\boldsymbol{\sigma_{ho}}$ is our best estimate of the lateral insitu stress. A number of techniques are available for identifying the lateral stress, and curve matching has been used to justify the choice made.
5. $\boldsymbol{\sigma_{vo}}$ is our judgment of the overburden stress.
6. $\mathbf{k_o}$ is the coefficient of earth pressure at rest, being the ratio of the effective lateral stress to the effective vertical stress, using the results in previous columns.
7. **OCR** is over consolidation ratio. This is derived using a relationship suggested by Wroth (1984) – see Appendix D.

Table 3.2 Parameters associated with strength

Test **BH1**	**Date**	**Depth** (mBGL)	c_u (kPa)	p_f (obs) (kPa)	p_f (calc) (kPa)	p_{lim} (kPa)	I_r	**OCR**
Test 1	15-Sep-14	9.80	153	315	452	1209	140	4.9
Test 2	15-Sep-14	15.30	298	543	722	1985	70	7.6
Test 3	16-Sep-14	20.00	251	564	864	1891	60	4.7
Test 4	17-Sep-14	25.00	327	849	1056	2499	83	5.2

Notes on table 3.2

1. c_u is undrained shear strength from the slope of a plot of the natural log of the current shear strain versus total pressure (Gibson & Anderson, 1961).
2. p_f (obs) is observed yield stress, the point where the loading response becomes noticeably curved.
3. p_f (calc) is calculated yield stress, the point where the curve fitting procedure indicates the loading response first becomes fully plastic.
4. p_l is limit pressure. When the test is undrained it is the intercept of the plot used to derive the undrained shear strength.
5. I_r is rigidity index, G/Cu where G is shear modulus at yield. The inverse of I_r is the shear strain at failure.
6. **OCR** is over consolidation ratio using a relationship adapted from Wroth (1984).

Table 3.3 Linear and non-linear parameters for deriving shear modulus

Test name BH1	**Depth** (mBGL)	**G_y** (MPa)	**Loop No.**	**G_{ur}** (MPa)	**Constant α** (MPa)	**Exponent β**	**G_s for $\gamma = 10^{-4}$** (MPa)	**G_s for $\gamma = 10^{-3}$** (MPa)	**G_s for $\gamma = 10^{-2}$** (MPa)
Test 1	9.8	21.4	1	30	4.897	0.706	73	37	19
			2	30	4.660	0.681	88	42	20
			3	26	3.840	0.657	90	41	19
Test 2	15.3	20.7	1	37	7.441	0.740	82	45	25
			2	32	6.322	0.713	89	46	24
			3	29	5.133	0.677	101	48	23
Test 3	20.0	15.0	1	28	3.595	0.649	91	41	18
			2	25	3.585	0.644	95	42	18
			3	24	3.394	0.637	96	42	18
Test 4	25.0	27.0	1	48	10.669	0.738	119	65	36
			2	39	8.055	0.702	125	63	32
			3	40	7.701	0.699	123	62	31

Notes on table 3.3

1. G_y is secant shear modulus at the plastic threshold. It is derived rather than measured.
2. G_{ur} is modulus obtained by taking the slope of the chord bisecting a cycle of unloading and reloading. This can only be shear modulus if the material response is linear elastic.
3. Due to the non-linear elastic characteristics of the soil, secant shear modulus is given by a power law of the form $G_s=\alpha\gamma^{\beta-1}$ where α and β are discovered from a plot of reloading data on log scales.
4. If the response is linear elastic then $\beta = 1$ and α would be identical to G_{ur}, quoted in the first column.
5. Tangential modulus G_t is given by a power law of the form $G_t=\alpha\beta\gamma^{\beta-1}$
6. For comparison purposes, secant shear modulus parameters are given at three plane shear strain levels, γ of $1x10^{-2}/10^{-3}/10^{-4}$, but any value of shear strain can be used in the range 10^{-4} to 10^{-2}. All these modulus values are G_{hh}.
7. To quote values for secant Young's modulus E_s in the *axial* strain range 10^{-4} to 10^{-2} use the following relationship: $E_s = 2\alpha(1+v)\,(\gamma\sqrt{3})^{\beta-1}$ where *v* is Poisson's ratio.

Fig 3.1 Cavity reference pressure vs depth

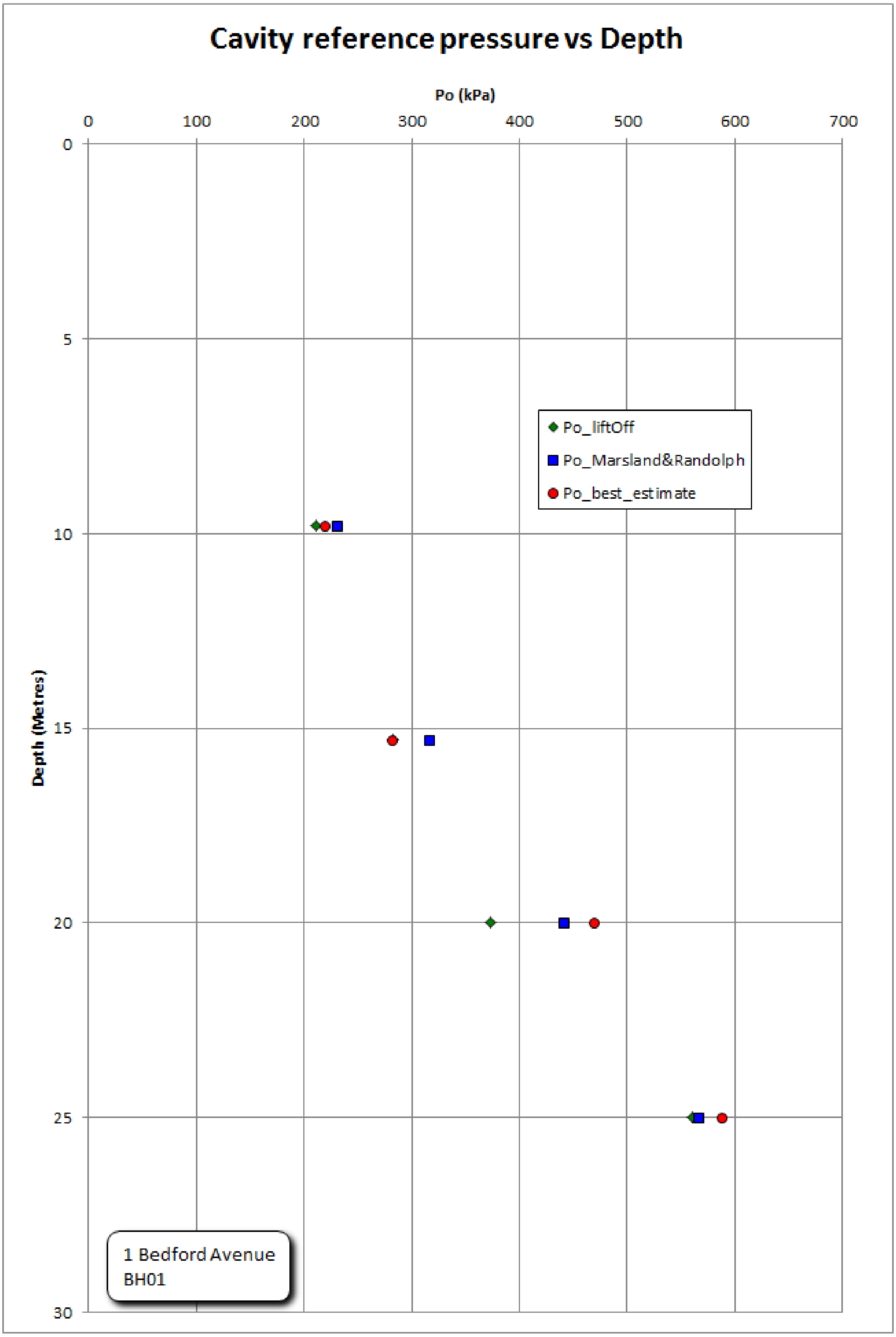


Fig 3.2 Coefficient of earth pressure at rest vs depth

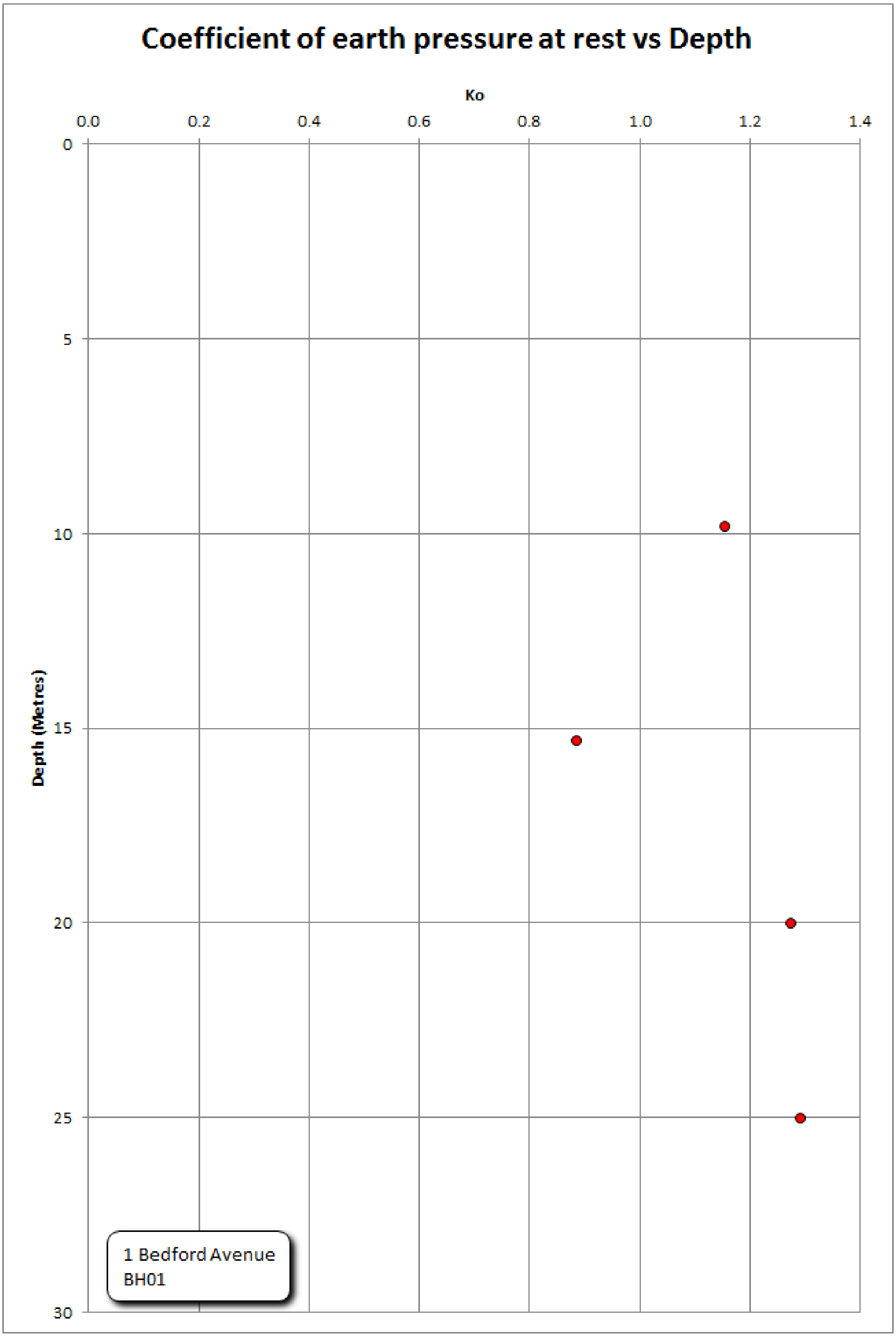


Fig 3.3 Undrained shear strength vs depth

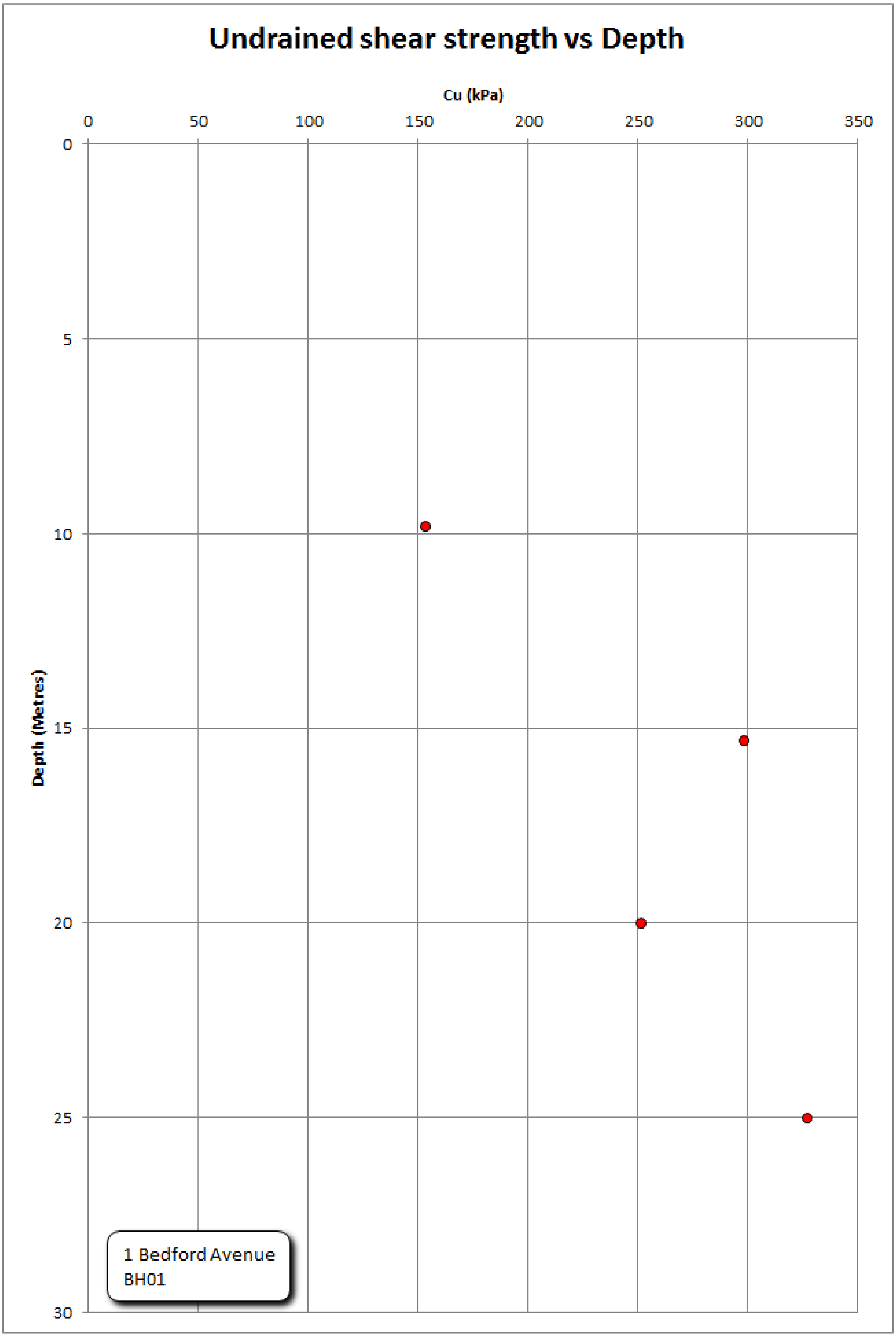


Fig 3.4 **Total limit pressure vs depth**

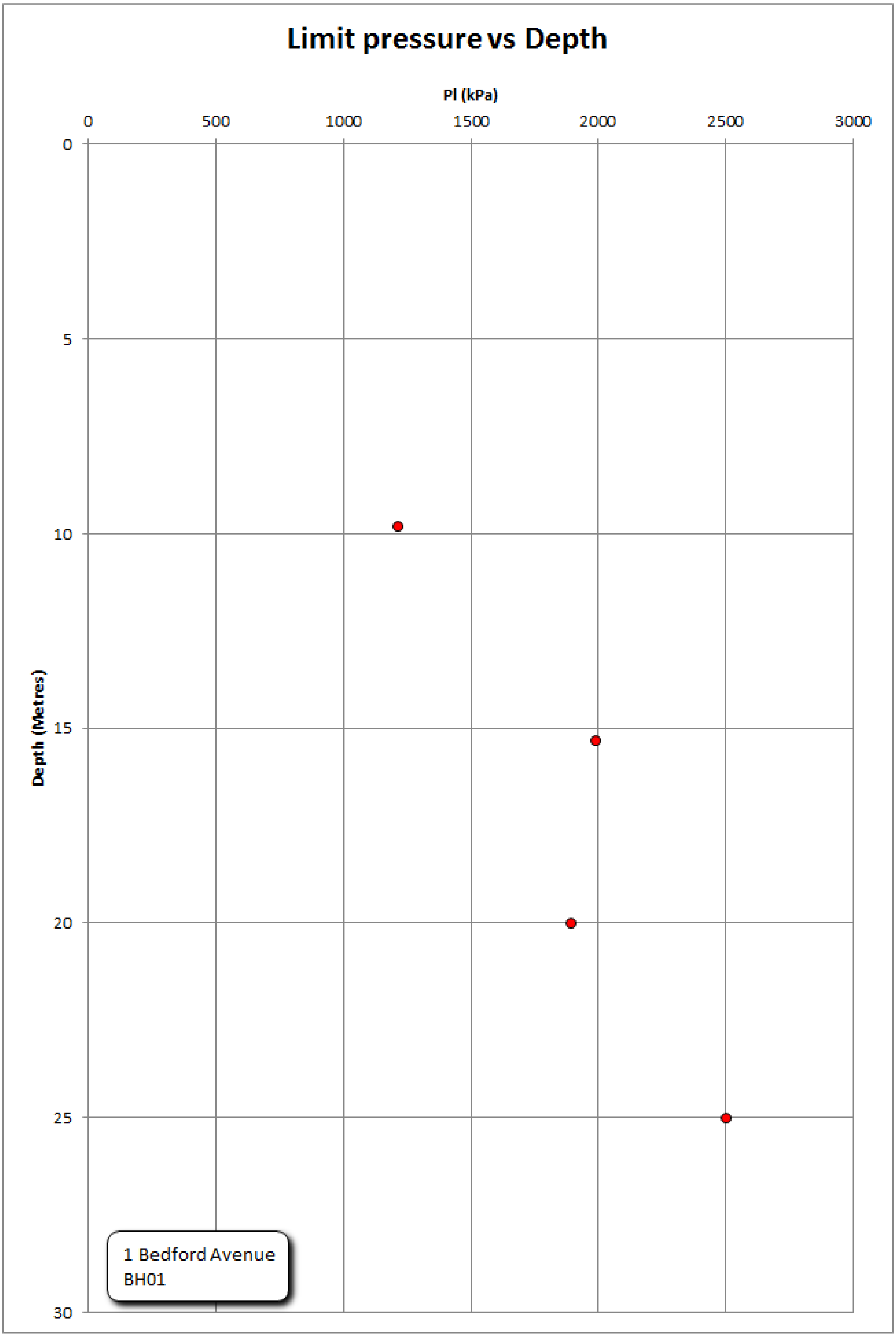


Fig 3.5 **Total yield stress vs depth**

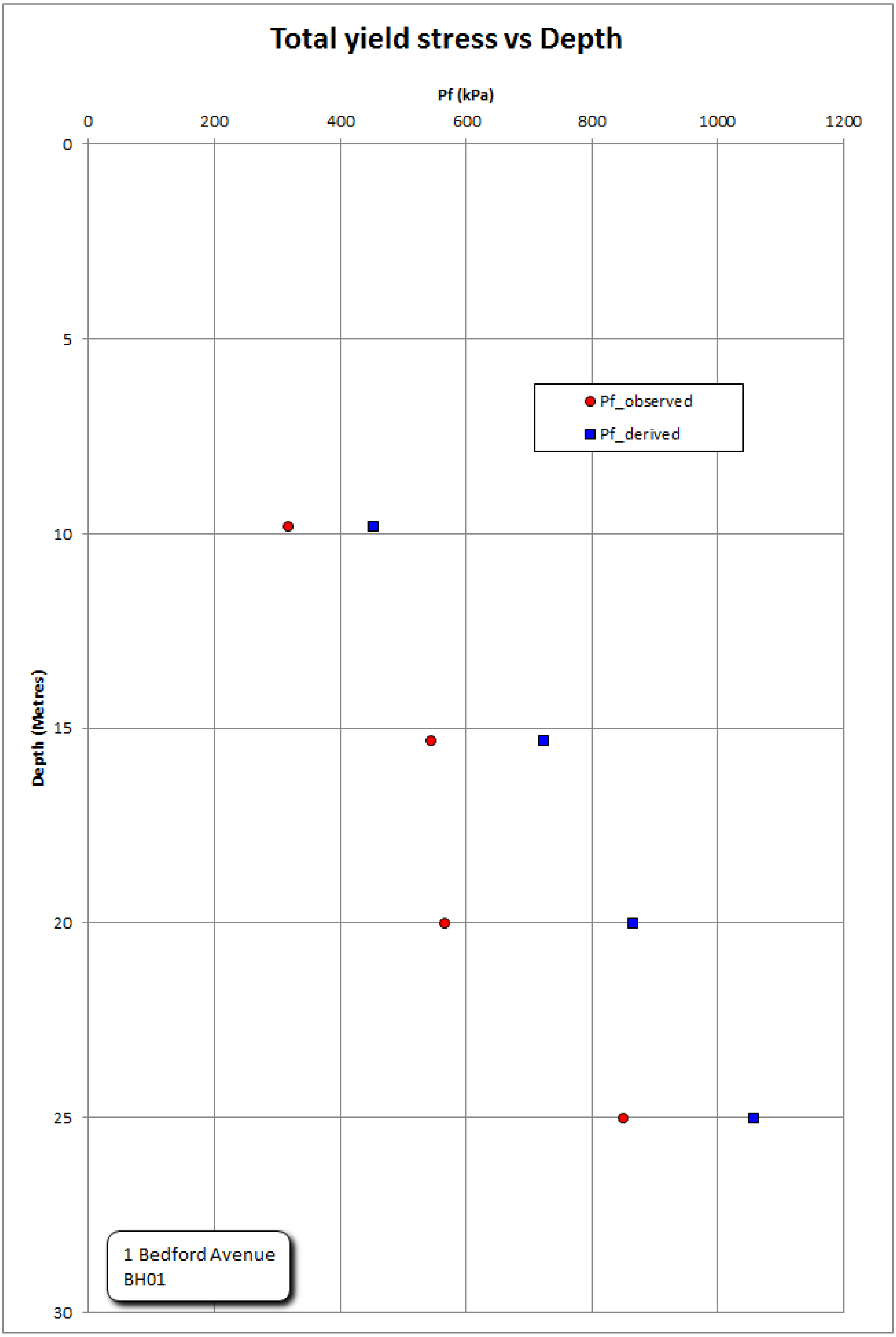


Fig 3.6 Secant shear modulus vs depth

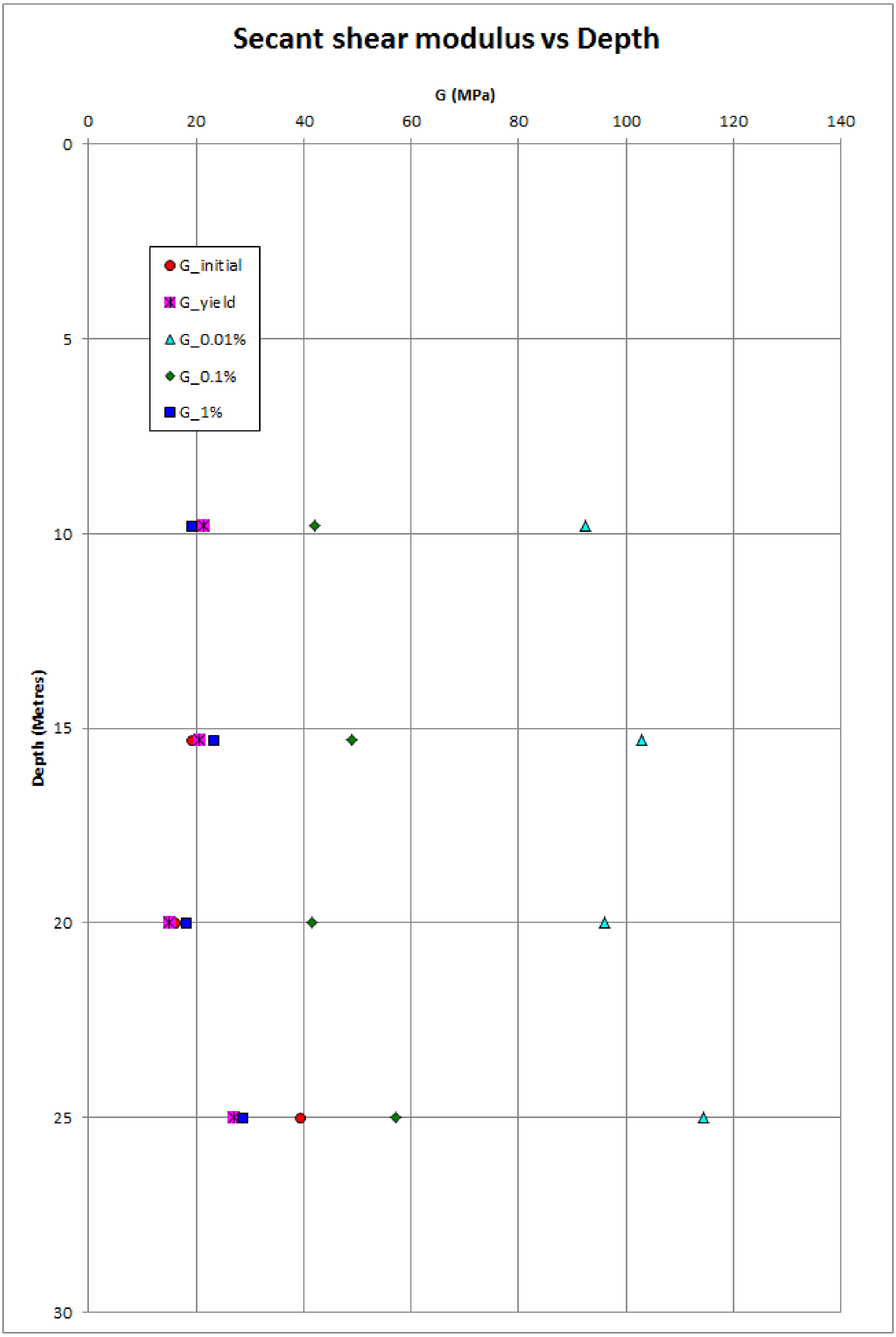
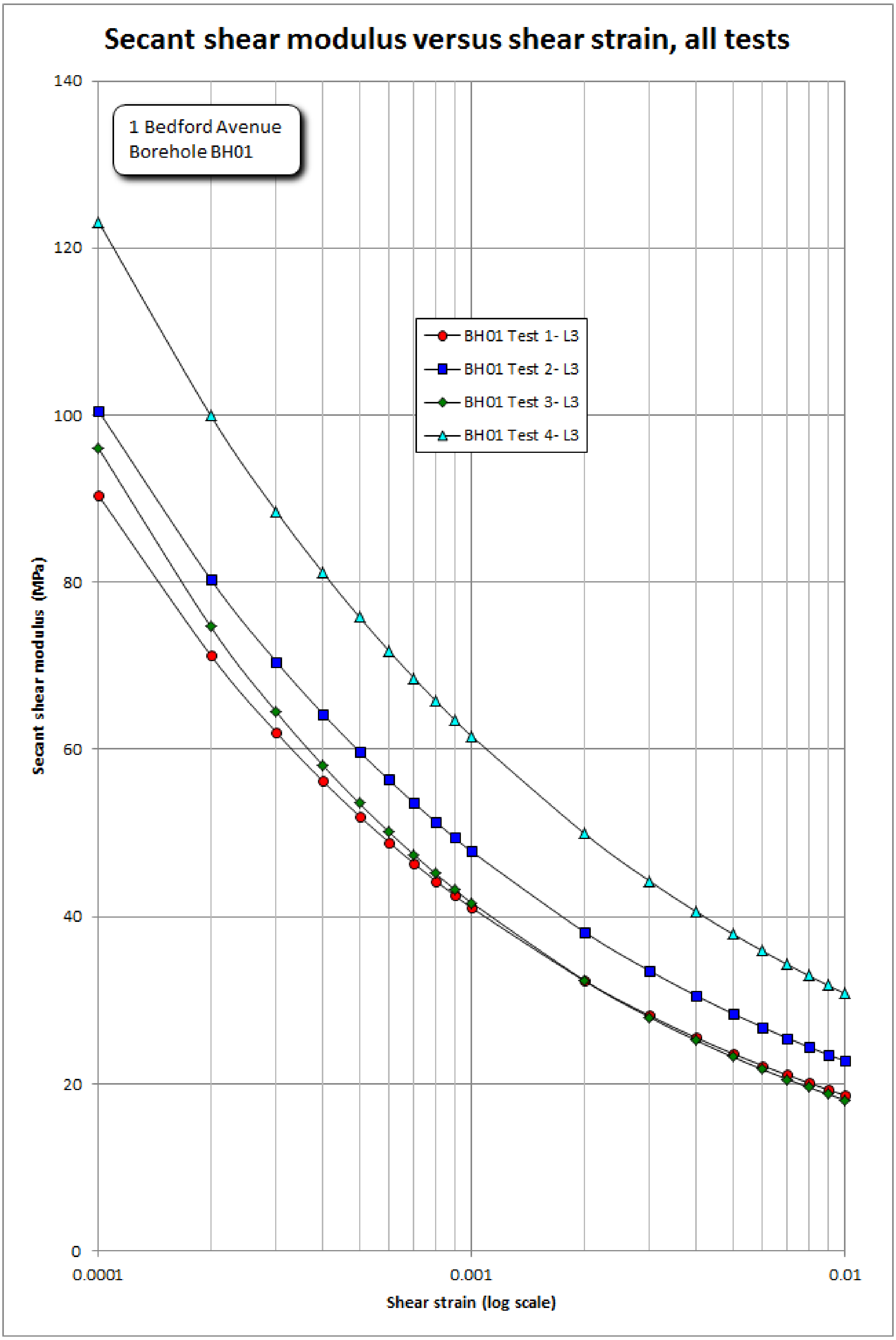
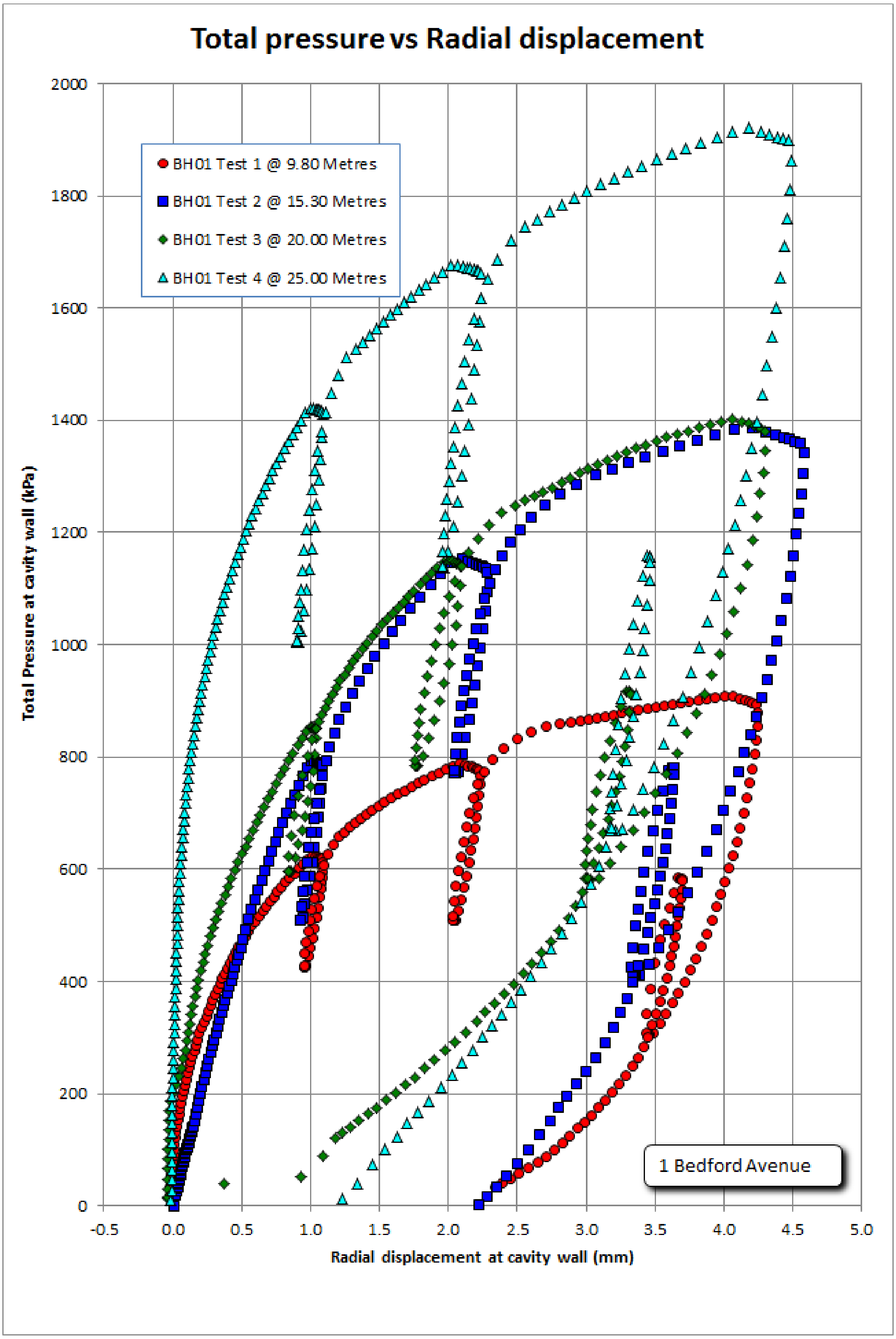


Fig 3.7 Secant shear modulus vs Shear strain



4. Field Curves

Fig. 4.1 All tests on common axes



APPENDIX A DESCRIPTION OF THE EQUIPMENT

1 The Soft Ground Self Boring Pressuremeter SBP

It is a probe about 83 millimetres in diameter and 1.2 metres long. Approximately 0.5m can be expanded by dry nitrogen gas and a typical test will expand the instrument by 10%.

Fig A.1 The Self Boring Pressuremeter without a Chinese lantern

The expansion is monitored by three or six followers, depending on the version of the probe used. These are conventionally referred to as 'strain arms' or more usually 'arms'. They are spaced evenly around the middle of the expanding test section. The arms are forced to follow the movements of the membrane by strain gauged leaf springs, and hence radial expansion is converted to an electrical output.

The internal pressure is measured by a strain gauged cell within the instrument. A further two cells are attached to the membrane, 180° apart, and these measure the changes in pore water pressure during the test.

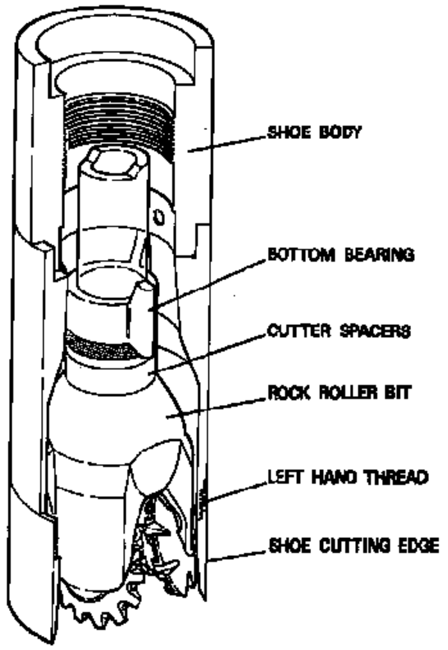


Fig A.2 The rock roller configuration

Conventionally, the membrane covering the expanding portion of the instrument is in two parts. The inner layer, which is sealed, is made of polyurethane and is about 1.25mm thick. This inner skin is then covered by an outer layer, which because of its appearance when the instrument is inflated is known as a 'Chinese Lantern' (CHL). The CHL is made up of stainless steel strips bonded to a thin rubber skin; it has two main tasks - to take the frictional forces that occur when the instrument is being bored into the ground, and to provide some protection from inclusions that might otherwise puncture the inner membrane.

The foot of the instrument is fitted with a sharp edged internally tapered cutting shoe. When boring, the instrument is jacked into the ground, and the material being cut by the shoe is sliced into small pieces by a rotating cutting device. It is a shearing process. The distance between the leading edge of the shoe and the start of the cutter is important and can be optimised for a particular material. If too close to the cutting edge the soil experiences some stress relief before being sheared. If the cutter is too far behind the shoe edge then the instrument begins to resemble a close ended pile. In stiff materials the usual setting is flush with the cutting shoe edge. The cutting device takes many forms. In soft clays it is generally a small drag bit, in more brittle material a rock roller is often used.

Fig A.3 The SBP ready to use

The instrument is connected to the jacking system by a drill string. This is in two parts, an outer casing to transmit the jacking force and an inner rod to rotate the cutter device. The casing is smaller than the maximum instrument diameter and the drill string is extended in one metre lengths as necessary to allow continuous boring to take place.

The cut material is flushed back to the surface through the instrument annulus. Normally water is used but air and drilling mud can also be used if appropriate.

The self boring method has been well documented and a complete description of the instrument and its test can be found in the references.

There is a watertight compartment at the lower end of the probe containing analogue and digital circuitry. All transducers in the probe are read once every five seconds, and the result is output as digital numbers in ASCII format via an RS232 compatible serial link. All the signal conditioning is carried out in the probe itself, so the pressuremeter is unaffected by changes to external equipment including the cable.

The weak rock self boring pressuremeter (WRSBP) uses the same probe as the SBP but with a tougher (and thicker) membrane. Rings and sleeves on the SBP instrument are substituted with similar items of a larger diameter. The crucial difference is that the cutting head now makes a hole about 1mm greater in diameter than that over the membrane.

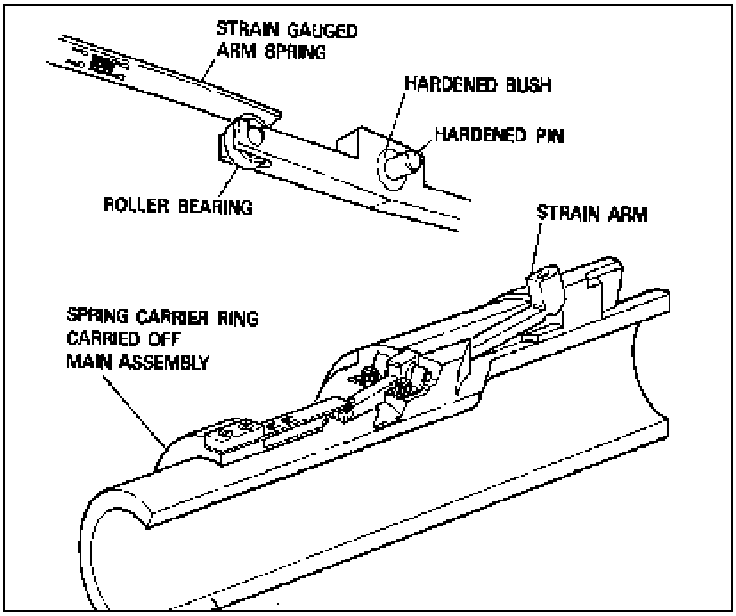


Fig A.4 The arm and spring arrangement

This one change allows the instrument to penetrate ground of the strength of very weak rock. Because such material requires higher loads to fail it, the instrument is permitted to go to 10MPa. The same configuration may be used in softer ground if it is thought to contain the occasional hard or sharp piece, or if there is a lack of kentledge, as was the case for these tests.

2 Electronic Interface Unit (EIU)

All pressuremeter hardware is powered by a single 12 volt vehicle battery. The battery is connected to the EIU, which introduces some protection and distributes the power to a number of outlets, including one for the pressuremeter. The returning signals from the pressuremeter connect to the same socket. The digital signals pass through an opto-isolation circuit and are then made available on two identical sockets for connection to the serial port of a computer. There is also an analogue signal representing the mean output of all the arms.

The unit has a panel meter switchable to read either battery volts or the analogue signal.

3 Strain Control Unit

The Strain Control Unit (SCU) is a box of electronics that controls the rate at which gas is supplied to the self boring pressuremeter. It can be arranged to inflate the pressuremeter at a constant rate of strain (rather than the more usual constant rate of stress). From a soil mechanics point of view tests carried out at a constant rate of expansion are more desirable, in that significant details of the shear stress/shear strain curve are suppressed or distorted during a stress controlled expansion.

Figure A.5 The Strain Control Unit

The SCU uses specially modified magnetic valves, which are controlled to operate in response to the strain signals returning from the instrument in the ground. Ten constant rates of strain are available between 0.1% per hour and 2% per minute, increasing and decreasing. In addition, the unit is able to hold the strain to a constant value for an indefinite period. This is useful when carrying out tests to determine the horizontal consolidation characteristics of clay. If at the end of a normal quick undrained expansion the strain is fixed whilst the excess pore water pressures are allowed to dissipate then a simple closed form solution leads to the derivation of c_h.

Not all the test is conducted at a constant rate of strain. The initial part of the test, before yield, is essentially a situation where large pressure needs to be applied before any displacements become apparent; This part of the test curve is extremely important and needs to be well defined by a number of readings.

The manner in which this is achieved is by limiting the maximum rate of pressure increase. There are two control mechanisms in the SCU, one over strain and one over pressure. The maximum rate at which pressure can be supplied to the instrument is a user-selectable option, with a number of possible settings between 10kPa and 300kPa per minute. In a situation where the strain rate was set to 1% per minute but the pressure rate was set to 10kPa per minute, then the pressure rate setting overrides the strain rate and the test is carried out at a constant rate of stress.

The effect of these two control mechanisms is that when the response from the ground is elastic the test is *stress* controlled. When the ground is deforming plastically then the test is *strain* controlled.

4 Pressure Control Panel

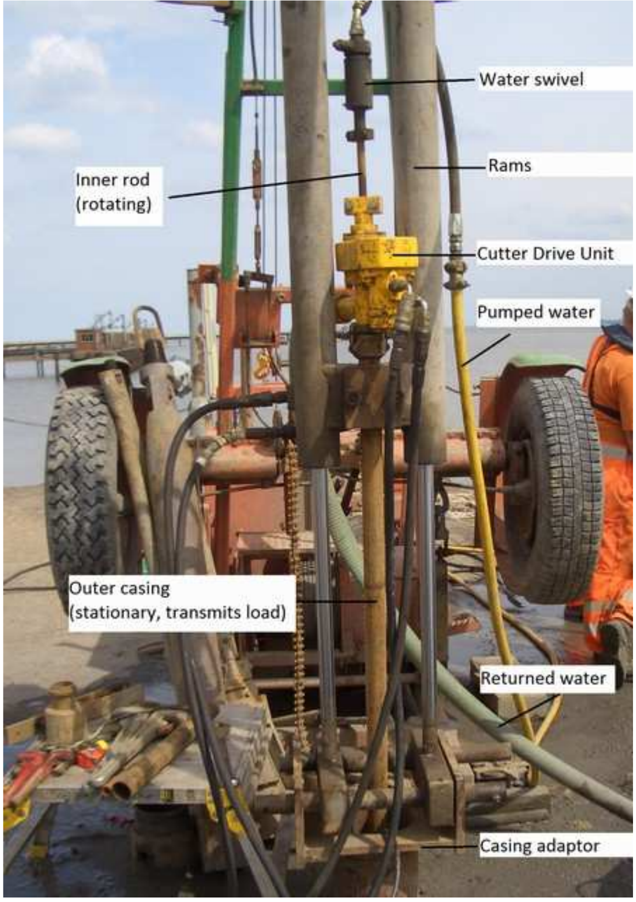
The Pressure Control Panel (PCP) consists of a hand operated regulator, a standard test gauge and a number of valves. It is used to monitor, and if necessary control, the gas supply to the Pressuremeter. In general the panel is used to calibrate the pressure transducers in the instruments and to replace the Strain Control Unit in the event of a breakdown.

5 Data Logging / Analysis Software

Software developed by Cambridge Insitu is used to log the data during the test, and for analysing the results subsequently.

For the expansion test the logging software stores the incoming data, displays the pressure/expansion curve in real time, and provides a text file output of the test data in engineering units. This file is read directly by the analysis program, but can also be read by any of the common spreadsheet programs.

Fig A.6 SBP drilling system



For expansion tests there is dedicated software providing routines to implement a number of standard analyses. The analyses tend to be graphically driven, meaning that the analyst identifies and marks significant parts of the curve, either for breakpoints or slope. The final screen for the analysis is then output as hardcopy backup for the decisions made.

6. Stand-Alone Drilling System

The SBPM can be bored into its test position with the assistance of a cable percussion rig and a cased hole. The system consists of an adapter for the casing, to which is pinned a set of hydraulic rams. These are used to jack the outer casing of the SBP and hence the instrument into the ground whilst a small hydraulic motor (Cutter Drive Unit, CDU) rotates the inner drill string (fig A.6).

Reaction for the jacking comes from the skin friction acting on the water well casing placed by a cable percussion rig. Power for the rams, the cutter drive unit and the water pump used to slurry the cut material is provided by a portable hydraulic power pack.

APPENDIX B THE CALIBRATION PROCEDURE

INTRODUCTION

There are eight aspects to the calibration of the pressuremeter:

1. Scale factors
2. Reference (‘zero’) outputs
3. Membrane stiffness
4. Instrument compliance
5. Membrane thinning
6. Displacement compliance
7. Instrument straightness
8. Repeatability (or how much effort should be devoted to calibrations)

After presenting the background to the calibration procedures the actual calibrations used on this contract are summarised.

1. Scale Factors

The transducers in the pressuremeters are based on full bridge strain gauge circuits. Any such transducer produces an output dependent on the voltage being applied to it, the stress that is deflecting it and the amplification or buffering between it and the recording system.

The instrument contains electronic devices that provide a regulated voltage to the transducers and amplification of the resulting output signals. Because this electronic conditioning is a fixed part of the system it is not mentioned when presenting calibrations. The electrical output of the transducer, in volts, is quoted only as a function of the deflecting stress. This function is termed 'sensitivity' and gives the scale factor for deriving pressure or displacement from the transducer electrical output.

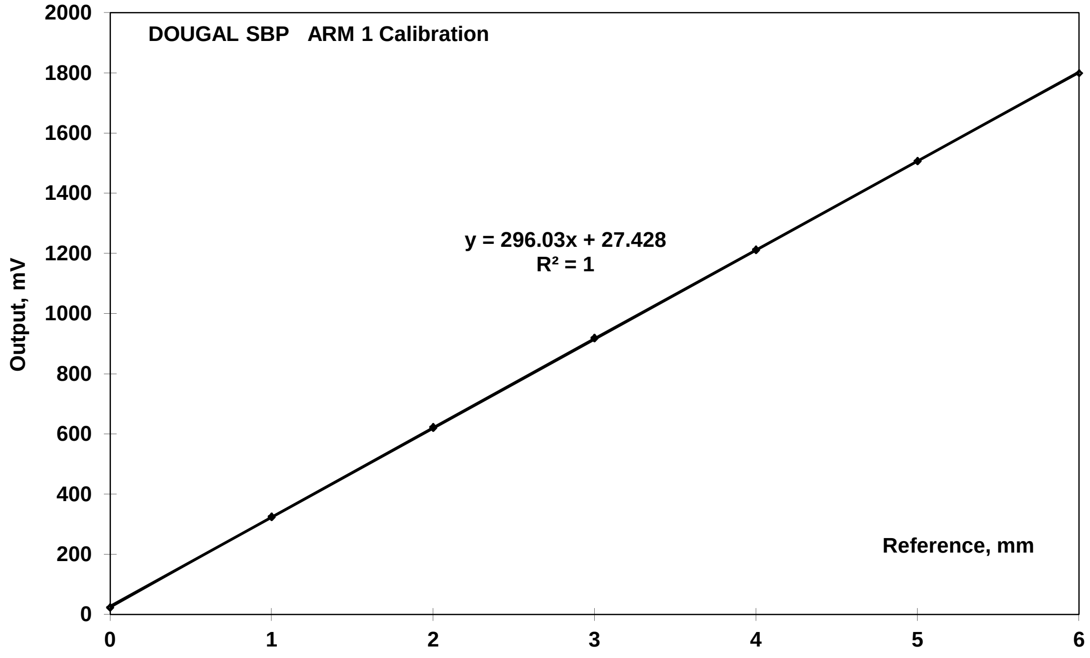
Although the output of the transducers is quoted in volts, the true output of the system is a digital data stream of ASCII encoded numbers which represent volts. This signal can be connected directly to the serial port of a small computer. All variables associated with producing the final digital output from the strain gauge signals are a function of the pressuremeter itself, and are independent of external changes such as replacing the cable.

When using the sensitivity calibrations to convert readings from volts into engineering units we make two important assumptions about this output; that it is linear and that the hysteresis is negligible. The calibration procedure needs to provide evidence that these assumptions are reasonable.

The displacement measuring system is often referred to as 'the arms'. The arms are calibrated by mounting a micrometer above each in turn and recording the output for a given deflection. When calibrating the instrument it is necessary to plot these readings for both an increasing and reducing deflection. The difference at a given point between increasing readings and reducing readings is a measure of the hysteresis. The worst case figure is noted, and steps are taken to reduce the friction in the system if the hysteresis is outside an acceptable limit - normally 0.5% of the sensitivity.

The slope of the best fit straight line through all the points is used to quote the arm sensitivity - as an output for a given deflection in units of millivolts per millimetre (mV/mm). Figure B.1 is an example.

Fig B.1 An example of an arm calibration



There is an additional output signal from the self boring probes which is an analogue representation of the average displacement signal. This is used in conjunction with a Strain Control Unit to control the gas pressure supplied to the instrument during a test. The average strain signal is separate from the pressuremeter digital outputs and is set to give a 0 to 600 millivolts change for a 0 to 10% increase in the instrument diameter. This implies that the sensitivities of the arms be broadly similar, within 5% of each other.

Positions for trimming resistors are provided in the instrument so that the sensitivity of the arm signals can be set. This is done by soldering high quality fixed resistors across the strain gauge bridge circuit. It is the only occasion when the absolute sensitivity of the strain gauge circuits is important.

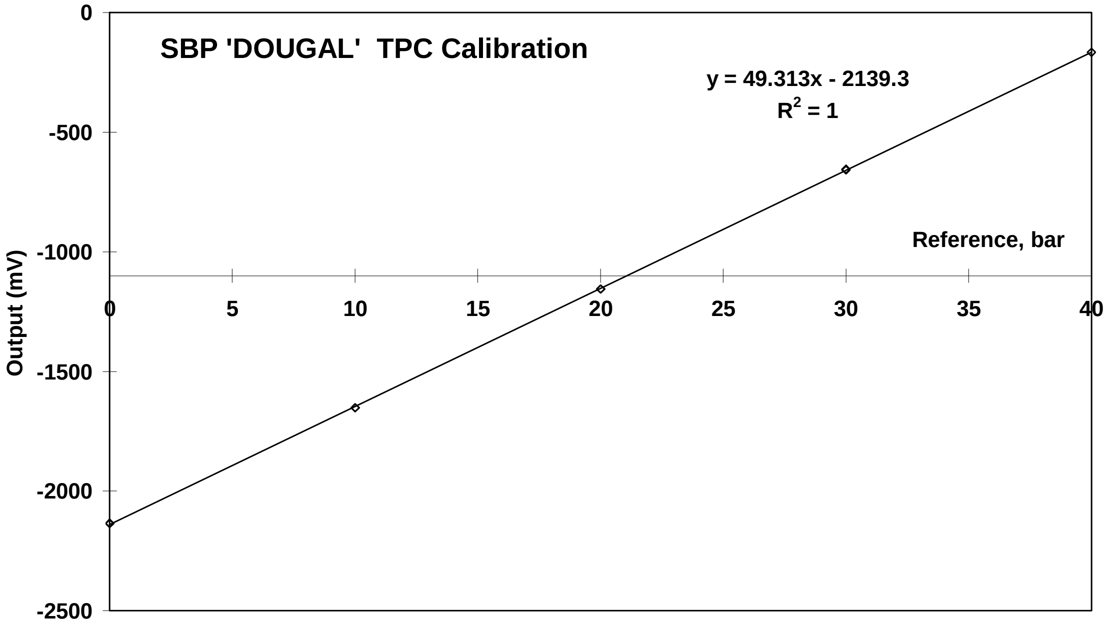
For the pressure measuring circuits the maximum possible sensitivity is desirable, the only requirement is that the sensitivity be known and be linear and stable.

The sensitivity of the internal pressure cell is determined by placing a large metal cylinder over the membrane, and applying a known gas pressure to the inside of the instrument. The gas pressure being applied is measured by a standard test gauge.

As with the arms, the readings are plotted, the hysteresis noted, and the best fit straight line drawn through the plotted points.

The pore water pressure transducers fitted to an SBP are calibrated in one of two ways. The most usual is to use a special calibration cylinder that seals to the outside of the membrane and allows *external* pressure to be applied to the instrument. Alternatively, prior to the pore pressure cell caps being fitted, the cells can be calibrated by applying *internal* pressure to the probe. Whatever system is used, the output of the two transducers is recorded and plotted as described above for the total pressure cell. See fig B.2.

Fig B.2 An example of an SBP pressure cell calibration.



Pressure sensitivities are quoted in units of millivolts per MegaPascal, whatever the actual units of the standard test gauge used to carry out the calibration.

2. Reference (‘zero’) outputs

The other parameter that the transducers have is a known output for an 'at rest' position. For the pressuremeter this is the value of the outputs produced by the circuits with atmospheric pressure on the inside of the instrument, and the displacement measuring system at the initial radius position. This is called a little misleadingly ‘zero’.

The absolute value of this figure is unimportant - it is not necessary or desirable that the figure be zero volts for the zero stress position, just that it be known. For practical purposes, as the analogue to digital converter can only output a number between -3.2767 and +3.2767, the ‘at rest’ readings tend be about minus one volt to allow the largest possibly range. There is one exception to this - the SBP requires that the average zero outputs of the arms be within plus or minus 50 millivolts of zero volts. This comes from the need to use a Strain Control Unit to carry out a test. The SCU uses the mean displacement signal from the instrument, and can only accommodate a limited offset from zero volts. Instruments which do not use an SCU to drive the expansion can ignore this restriction.

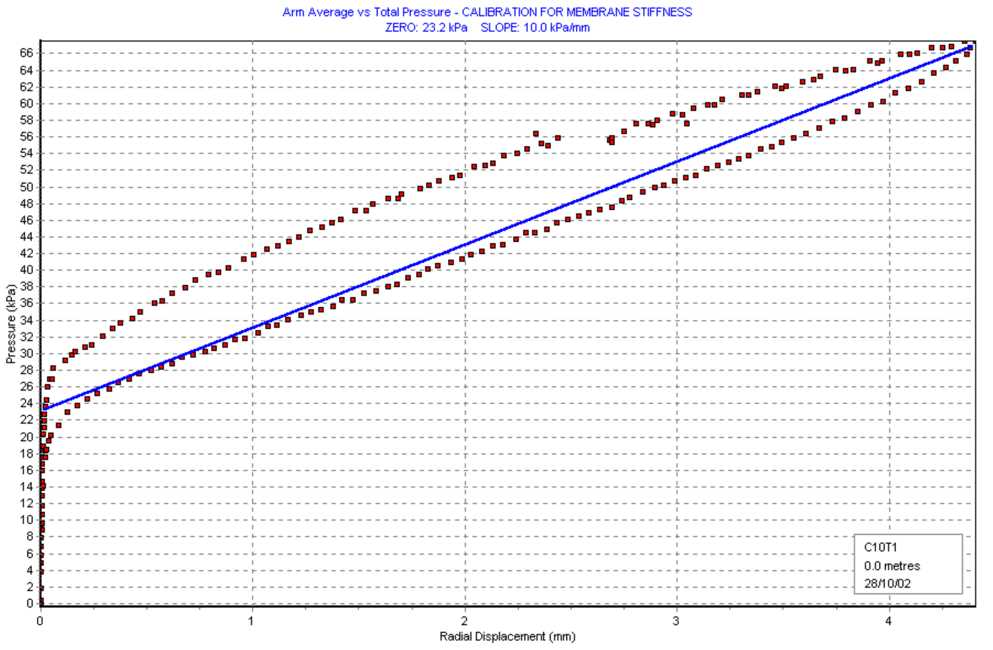
Adjustment positions are provided in the instrument for setting this 'zero' output.

It is normal to take zero readings both at ground level and also immediately prior to carrying out a test. A significant change between zero readings must be investigated. 'Significant' would mean a change of 30 millivolts from the last set of zero readings. It is not unusual for shifts of a few millivolts to occur from day to day. It is important that the zero readings be stable when viewed over a period of a few minutes.

3. Membrane stiffness

The membrane that is expanded by the instrument has its own initial tension requiring a finite pressure to move it. The readings measured by the stress cells need to be reduced by this pressure in order to determine the net stress being applied to the ground.

Fig B.3 An example of a membrane stiffness calibration



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The term 'membrane' is used here to mean both the sealed elastic sleeve over the instrument that contains the pressure, and the rubber and stainless steel protective sheath that sometimes covers this. The sheath is known as the 'Chinese Lantern'.

The membrane correction has two components - the pressure to move the membrane from its position at rest on the instrument, and a second component that depends on the radial expansion.

The technique for obtaining the correction data is to pressurise the instrument in free air, using the same rate of expansion as would be applied during a test. The slope and the intercept on the pressure axis of the graph produced by this test give the membrane correction information for each arm.

Knowing that the membrane does not necessarily possess isotropic properties, it has been customary to derive a different set of figures for each arm position. However recent work indicates that an unconfined inflation in air exaggerates any variation in membrane properties; an average correction factor is more appropriate.

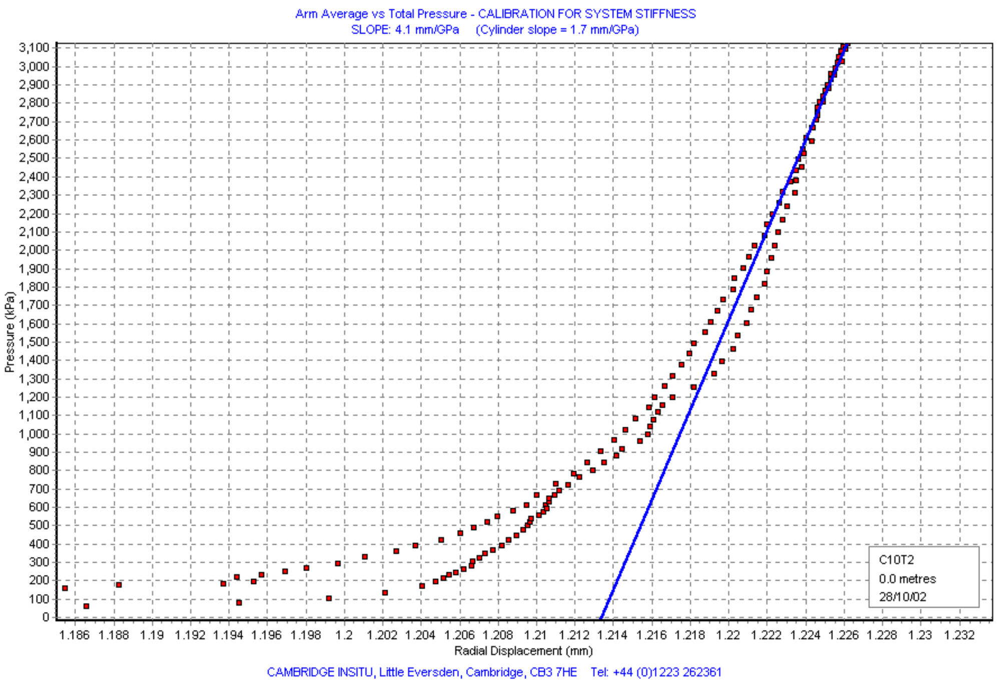
The membrane correction data is quoted as a pressure in kPa to move the membrane from its rest position together with a second pressure in units of kPa/mm representing the pressure increase necessary to maintain the inflation. Typical correction figures might be 20 kPa and 7.0 kPa/mm. See fig B.3 for an example.

4 Instrument compliance

The instrument will deform as a consequence of the pressure being internally applied. Put simply, the instrument stretches. Because the displacement measuring system uses the body of the instrument as a reference, movements of the body are seen as apparent displacements of the membrane; some ingenuity is needed to immunise the displacement measuring system from this problem. This system compliance has implications for the measurement of shear modulus, and it can become a significant source of error when measuring very high modulus values.

There are a number of effects to consider but they are collectively determined using a single procedure. The correction value arrived at is known somewhat inappropriately as 'membrane compression'.

Fig B.4 An example of a membrane compression calibration



The procedure conventionally suggested for obtaining correction data for 'membrane compression' is to inflate the pressuremeter inside a number of cylinders of different bores; by comparing these known bores with the displacements actually obtained from the pressuremeter then a correction curve can be obtained. Because the correction has been assumed to be a function of membrane *thickness*, then it is expected that the effect reduces as the membrane thins. In other words, it is treated as a strain dependent variable, and a change in membrane means a new correction curve must be derived.

For the Cambridge family of pressuremeters real membrane compression, that is the membrane changing in thickness as a direct result of the pressure differential across it, is almost too small to be measurable. There are a number of other factors to consider of significantly greater magnitude than membrane compression.

Inflating the instrument inside a steel cylinder will in theory provide data on the magnitude of these effects. However a separate source of error, which is a function of the calibration procedure itself, then becomes apparent. The membrane is able to expand axially by a small amount, and as a result experiences a change in thickness which may not occur in the ground. Although steps can be taken to keep this axial movement to a minimum, it cannot be easily eliminated.

As a consequence of the poor fit of a calibration cylinder, and also of the relatively low coefficient of friction between the membrane and the steel by comparison with the membrane and the ground, the instrument will move about in the cylinder - its centre will not be the same as the centre of the cylinder. Only average radial movement can be derived from this calibration process, and it is not possible to obtain good data for each arm.

There is evidence that much of the correction is due to the Chinese lantern strips taking up the form of the cylinder, a process that would only occur in the ground if the material was good rock. This is the explanation for much of the initial curvature that occurs when an assembled probe is inflated inside a metal sleeve - it is a serious error to attempt to derive a correction factor from this part of the loading.

One approach is to take the membrane out of the correction loop by removing it altogether. A special cylinder is then fitted which seals to the body of the instrument, which is then pressurised. The displacement data which this test produces is used to determine the purely instrument related factors. Typically the data is reduced to a slope correction, on the order of 1 - 2 millimetres per GPa, and is a constant, being a function of the physical properties of the instrument.

The membrane is then fitted, and the instrument is expanded in the cylinder. The slope of the unloading path of the average radial displacement in this cylinder is used to obtain a value - it has been noted that the unloading path is much less unaffected by instrument movements.

The slopes obtained from the two methods are then compared. Typically they are the same within 1mm/GPa. This is to be expected. The bulk modulus of rubber is about 1GPa, and hence a membrane that is about 2mm in thickness will have a slope of 1mm/GPa. Further expansions inside other cylinders will not improve the quality of the correction so obtained.

To put the correction in context, a slope of 5mm/GPa (a relatively large correction) is equivalent to a modulus greater than 4GPa. Note that before the correction data is quoted the expansion of the metal cylinders themselves must be removed from the data. One indication of the magnitude of the correction is that the instrument compliance correction is usually smaller than the calculated deflections of the calibration cylinder.

The correction data can be used in two ways. Applied as 'mm per GPa' it can be used to correct individual data points before analysis; this is our practice. It can also be quoted as a system modulus, and hence be applied subsequently to modulus parameters determined from analysing uncorrected data.

5 Membrane thinning

During a test the pressuremeter membrane changes in thickness as a consequence of being stretched. This change in thickness can be calculated by assuming to a first approximation that the cross-section area of the membrane remains constant. The calculation is incorporated into the program that converts raw data into engineering units.

Note that the term 'membrane' includes the stainless steel protective sheath, and that the measurement made by the arms is the radial distance to the inside of the membrane.

Definition of Terms

2a	is the I.D. of the membrane at rest
2b	is the O.D. over the membrane at rest
2c	is the I.D. of the membrane expanded
2r	is the O.D. over the membrane expanded
t	is the thickness of the stainless steel sheath strips
d	is the measured movement of the strain arm
E	is the actual expansion of the membrane
L	is the length of the expanding membrane

Calculation

At rest the cross-section area of rubber = $\pi(b-t)^2-\pi a^2$

The expanded cross-section area of rubber = $\pi(r-t)^2-\pi c^2$

Because the rubber is incompressible, these must be equal:-

therefore $(b-t)^2-a^2=(r-t)^2-c^2$

Now:- $c=a+d$

and:- $r=b+E$

therefore $(b-t)^2-a^2=[(b+E)-t]^2-(a+d)^2$

$$\therefore [(b-t)+E]^2=(b-t)^2-a^2+(a+d)^2$$

$$\therefore E=\sqrt{[(b-t)^2-a^2+(a+d)^2]}-(b-t)$$

This is the two dimensional version of the correction. If the finite length of the membrane is taken into account then the correction becomes:

$$E=\sqrt{[L/(L+2d)][(b-t)^2-a^2]+(a+d)^2]}-(b-t)$$

This is the form in which the calculation is commonly applied to the data, with **2a**, **2b, t** and L being known from the manufacturer's data, and **d** being the measurement made by the displacement sensors during the test. For a soft ground self boring pressuremeter fitted with a polyurethane membrane and Chinese lantern:-

2a = 79.1 mm
2b = 84.1 mm
t = 0.18 mm
L = 455 mm

To apply the correction at a given expansion the *average* radius of the expanding membrane is calculated. This average is then entered into the equation and the ratio between the corrected average and the raw average is expressed as a scale factor. For probes with thicker membranes such as an HPD or weak rock version of the SBP, the scale factor lies between 0.89 and 0.92. For a soft ground SBP, with the thinnest membrane, it is about 0.95 at all expansions. The scale factor is then applied to the individual arm displacement outputs.

6. Displacement compliance

This is not so much a correction or calibration as a check on the mechanical performance of the self boring instrument (it is not applicable to a pre-bored probe such as the HPD). Using the external pressurising cylinder gives information about small movements of the strain arms under load. This mimics the situation in the ground where the instrument has the insitu lateral stress pressing against it prior to commencing the test. The presence of this stress can create small deflections of the strain arms. These deflections can create doubt about the precise point at which lift off is occurring.

Plotting the output of the strain arms as the pressure is removed during an external pressurisation test produces plots which can be compared with real test data. It will be observed that each arm has its own ‘signature’. Steps should be taken to keep these small strain movements to a minimum by attending to the seating of the displacement follower.

It is possible that recognising these signatures can help with assessing the precise moment when membrane lift-off occurs. However in this calibration procedure there are no penalties for small instrument deflections – in the ground these movements will change the external pressure because soil has stiffness.

7. Instrument straightness

The self boring instrument can become bent during operations due to the large forces applied when it is being jacked down. Before bringing the instrument on site it is good practice to check that the instrument is straight (within a small tolerance). The method for doing this is to support the instrument at the points where the membrane is clamped, and then to rotate the instrument whilst the run out is observed at a number of points. A form is supplied indicating the total runout at these points.

The instrument is never perfect, and it happens that frequently a consistent bias in the displacement system (especially in the vicinity of initial movement of the membrane) can be linked to a lack of straightness.

8. Repeatability (or how much effort should be devoted to calibrations)

Although it is important regularly to check the sensitivities of the strain gauge circuits, it is unusual for them to change markedly. Indeed it is common for the hysteresis to improve with use. 80% of the performance of a strain gauge bridge application can be predicted from its design; the calibration removes the uncertainty due to manufacturing tolerances, and can give early warning of impending problems in a particular circuit.

The pressuremeter test is concerned with making relative measurements, not absolute measurements. For example the SBP displacement measuring system will resolve movements of less than 0.5 microns over a range of 7 millimetres; the pressure measuring system will resolve changes of 0.5 kPa over a range of 5MPa. This resolution is considerably higher than can be seen with a standard micrometer or test gauge. To put it into context, 0.5 microns is approximately the wavelength of ultraviolet light. Obviously there is no practical possibility of checking by measurement a movement so small.

Hence the term ‘calibrating’ is inappropriate. What is done in practice is to check that the various sensors are linear over a number of relatively coarse steps or intervals. We assume that this linear behavior will be true for very much smaller changes.

For this reason alone, without considering additional sources of error such as the skill of the operator carrying out the calibration, the accuracy of the standard used to derive this linearity is of secondary importance. We would expect successive calibrations on the same sensor to be within 2% and would question a difference greater than 5%.

We also ignore secondary sources of error in this assumption of linearity, such as temperature change. When critical measurements are being made during a test, for example when taking a reload loop, it is reasonable to assume that the temperature remains constant.

Using spreadsheet software to present the results of the calibrations for sensitivity has become common practice. One benefit of this is that slopes can be calculated by linear regression routines; this ensures that different operators given the same set of data will derive identical calibration factors. The calibrations are presented as a tabulation of transducer output against a known reference, with the linearity and hysteresis quoted for each calibration step.

The membrane correction for the soft ground self boring instrument can change with use because the membrane absorbs water. Most of the change occurs the first time the instrument is put in the ground. In soft ground, where the stiffness of the membrane might be a significant factor in the measurement of the insitu lateral stress, it is advisable to keep the instrument in a tank of water whenever it is out of the ground. In any event, frequent checks on the calibration are sensible.

If the material is soft then membrane stiffness is important. If the material is extremely stiff then correcting for instrument compliance may be important. In between these two extremes, where the vast majority of pressuremeter tests in the UK are carried out, the contribution of the imperfections of the machine to the derived parameters is negligible.

9. Tables of calibration constants

3 Arm self boring pressuremeter:

Probe	Date	Arm 1	Arm 2	Arm 3	TPC	PPC A	PPC B
		mV/mm	mV/mm	mV/mm	mV/MPa	mV/MPa	mV/MPa
Dougal	11/08/14	304.1	292.4	311.8	342.1	429.4	422.0
Dougal	09/10/14	303.9	292.2	311.3	340.9	429.4	421.2

The highlighted values are the ones used on this contract.

10. Membrane and system compliance calibrations

Test Ref	Date	Probe	Zero	Slope	Compliance
			(kPa)	(kPa/mm)	(mm/GPa)
Z0204T14	02/04/2014	Dougal	21.0	8.1	***
Z0204T15	02/04/2014	Dougal	***	***	0.9

11. SBP straightness

Probe	Date	Point A	Point B	Point C	Point D	Point E	Point F
Dougal	01/04/2014	9	7	5	18	26	41

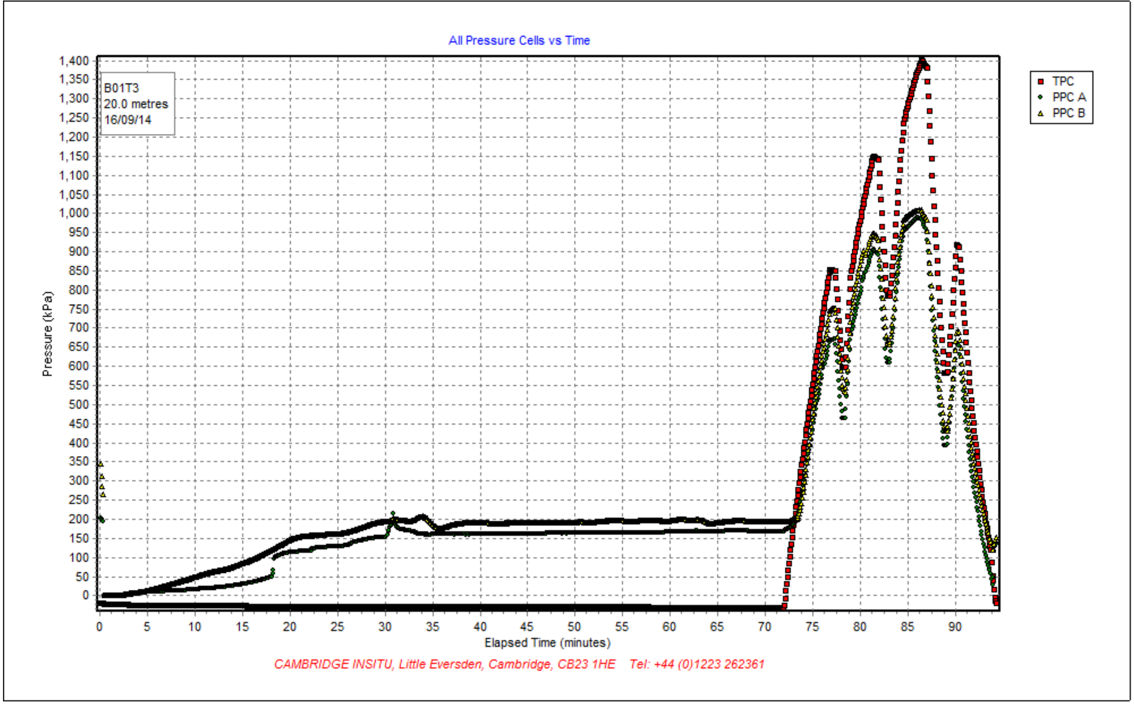
Notes : The values are the total run-out (in thousands of an inch) at various points along the body of the probe. Points A to C are within the expanding section of the probe. Points D to F are outside the expanding zone and F is the run-out on the first length of casing screwed to the probe.

APPENDIX C THE TEST PROCEDURE

C.1 Introduction

The SBP tests were carried out with a 3 arm Cambridge Self Boring Pressuremeter (SBP) with a diameter of 88mm over the membrane and an effective expanding length of 480mm. For all tests the probe was fitted with a cutting shoe that made a hole of 89mm diameter.

Figure C.1- Drilling and testing example, SBP pore pressure response



C.2 Drilling and placing the SBP

The SBP operation was conducted under a cut-down cable percussion rig using a proprietary system that exploited the kentledge offered by a driven length of water well casing. The flushing medium was water and the sequence of events was as follows:

1. The rig prepared a large diameter hole to a nominated depth approximately 0.5 metres above the intended test point.
2. The instrument was laid horizontally on a holding frame and a single length of casing and inner rod was added to the probe. The pore pressure cells on the probe were de-aired and covered to prevent evaporation. A line of zero readings were then taken from the data logging system. The pore water pressure response during the drilling operation was sometimes logged.
3. The instrument was lowered down the borehole using the rig winch, with lengths of casing added at intervals of about 3 metres.
4. Approximately 1 metre was self bored. The skin friction of the ground acting on the casing column gave the required kentledge. The down thrust was kept to the minimum consistent with good return water flow so that the probe entered the ground at a constant force. Typically a metre of self-boring in London Clay took about 20 minutes, but much

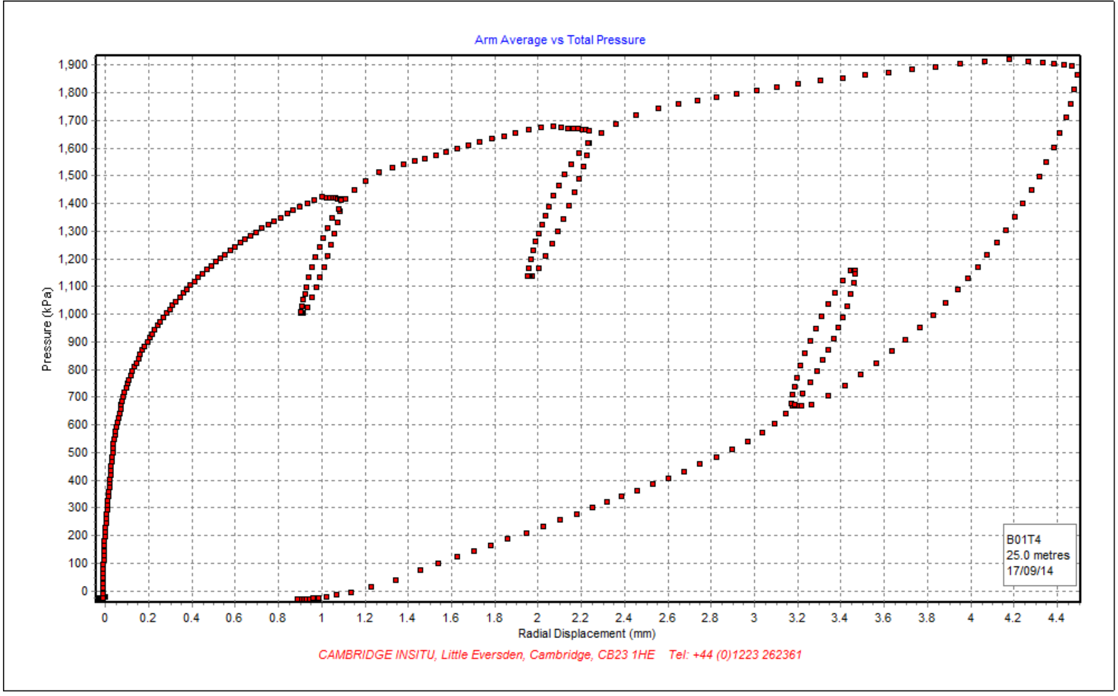
longer in the Lambeth mottled beds .

5. The return flush was observed and re-cycled.
6. Once at depth a test was carried out, with two unload/reload cycles and a reload/unload cycle on the final unloading..
7. After the test the probe was extracted from the borehole
8. The borehole was cleaned out and advanced by the rig to 0.5m above the next test depth. In the meantime the probe was cleaned and the cutting shoe edge checked for defects.

C.3 Expansion tests with the SBP

1. At the start of the test, gas pressure was applied to the instrument in constant small increments. This is the stress controlled phase of the test which ceases once the pressure being applied exceeds by some small margin the material yield stress.
2. Once the test cavity started to expand the gas pressure was adjusted to keep the rate of strain increase constant - 1% per minute is generally accepted as a sensible rate which is sufficiently fast to ensure undrained expansion in clays and not too fast for a drained expansion in sands.

Figure C.2 Example of SBP expansion test



3. Shortly after the cavity began to expand, between 1% and 2% cavity strain, an unload/reload loop was taken. The starting strain of the loop depended on the expansion being underway at all points around the membrane, and the pressure drop used depended on the current mobilised shear stress. This is not known exactly at this stage in a test, but it is possible to form a rough estimate. In general the pressure drop was made about the same as the estimate of the shear strength, relying on the fact that the material will respond elastically for twice this amount to take care of any errors in the estimate.
4. Before initiating the unloading for a loop, the pressure in the membrane was held constant for a short period, typically 30 seconds.
5. A second loop was taken between 3%-5% cavity strain, and a further loop was added on the final unloading.

6. The loading phase of the test ended when an average of 10% expansion of the test cavity had been achieved.
7. The complete unloading curve was then monitored, often with a reload/unload cycle.

C.4 Logging Rate

A line of data representing the output of all transducers was logged every 5 seconds.

APPENDIX D THE ANALYSIS PROCEDURE

This appendix gives details of the methods used to derive the results of pressuremeter tests on this contract. The text is illustrated with examples from the fieldwork.

1 Material properties from pressuremeter tests in soil.

There are two well-established approaches to the interpretation of expansion pressuremeter test data. The first, developed by Menard, uses empirical correlations to allow measured co-ordinates of pressure and displacement to be inserted directly into design equations. This approach depends on a standardised test procedure and a large data bank of pressuremeter tests correlated with observations of the response of finished structures.

The second approach, which will be described briefly here and is the usual way of interpreting the pressuremeter test in the UK, relies on solving the boundary problem posed by the pressuremeter test.

The aim of the pressuremeter test is to expand a long cylindrical cavity within an undisturbed mass of soil. Fundamental strength properties of the material can be deduced from measurements made of cavity pressure and displacement.

In practice no instrument can be placed into the ground without affecting the surrounding soil. In the case of a self-bored pressuremeter test the disturbance is generally within the elastic range of the soil and can be allowed for in the analysis procedure.

1.1 The pressuremeter test in soil - initially elastic response/failure in shear.

Consider that the soil is homogeneous, and shows simple elastic behaviour before failing in shear. The stress path followed by an element of soil adjacent to the cavity is given in fig 1.1 and the corresponding pressure /strain curve is shown alongside.

The radial stress, ideally at the insitu horizontal stress for a perfect installation, increases at the same rate as the circumferential stress decreases, regardless of whether the material is deforming under plane strain or plane stress conditions. The line 0 - 0 represents stress equality, so that in the ideal case considered here the point P_0 is the insitu lateral stress..

Once the radial stress increases above the insitu stress then the shear stress in the soil at the cavity wall will increase. If the insitu lateral stress is low, then it is possible that the circumferential stress would go into tension. However in this example the insitu stress is high enough to ensure that the shear stress limit is reached before tensile stresses can be generated.

The pressure necessary to initiate shear failure is denoted p_f in fig 1.1. After this pressure the strain rate shows a substantial increase, and the form of this part of the pressure/strain curve is a function of the shear strength of the material.

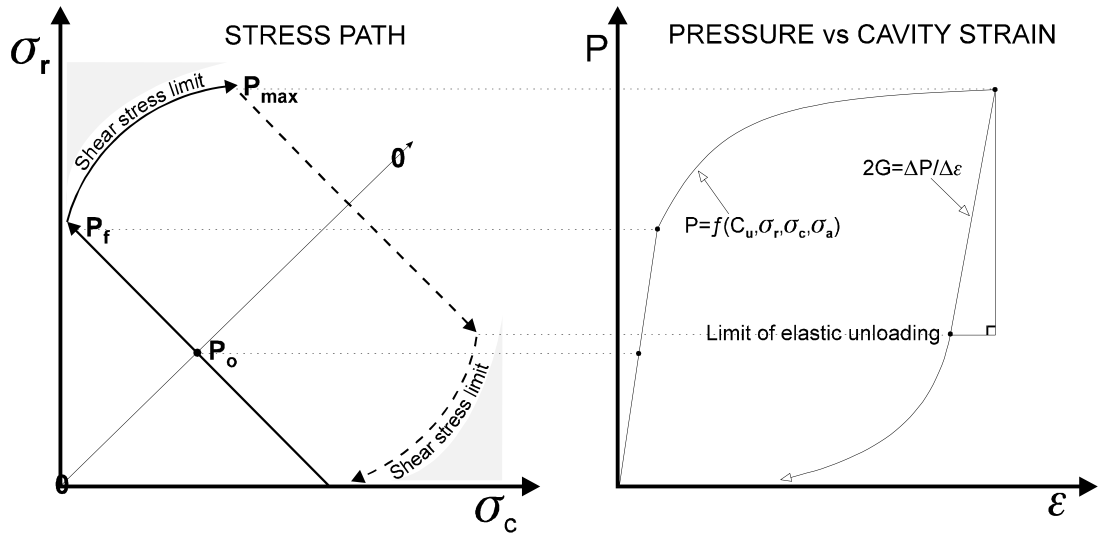


Fig 1.1 - Elastic Response followed by failure in shear

Radial stress and circumferential stress now increase together. If the shear stress limit is constant, and is not influenced by pressure, and if the material deforms at constant volume, then the failure shear strength can be determined by the analytical solution developed by Gibson & Anderson.

Before the shear stress limit is reached the pressuremeter response is elastic, both in loading and unloading. Assuming the soil deforms at a constant modulus and the installation is perfect then the slope of the initial loading path gives the shear modulus of the material, using the classic procedure of Bishop, Hill & Mott (1945). The diagram also indicates that reversing the direction of loading causes an initial elastic response giving an alternative means of deriving the shear modulus. This implies that small cycles of unloading and reloading taken anywhere in a test after reaching the shear stress limit can be used as a source of stiffness information (Hughes 1982).

As fig 1.1 suggests, the complete unloading of the pressuremeter can also be used to give strength and stiffness parameters comparable with those obtained from the loading path.

From the right hand side of the stress diagram it is apparent that the pressuremeter provides only a limited set of the necessary information for resolving the stresses and strains around the probe. Specifically it gives the changes in radius of the borehole wall (a special case of hoop strain) and the corresponding changes in radial stress at the borehole wall. There are no data for hoop stress or radial strain or movements in the vertical direction. Test procedures are chosen to allow the missing data to be inferred – for example an undrained expansion means shearing occurs at constant volume and hence changes of radial strain must be equal and opposite to changes in hoop strain. The unseen vertical axis data are rendered redundant by making pressuremeters long with respect to their diameter, allowing plane strain expansion to be assumed.

1.2 Defining strain

For a pressuremeter measuring the radius of an expanding cavity the conversion from displacement to strain is $[R-R_0]/R_0$, where R is the current radius of the cavity and R_0 is the original radius of the cavity in the insitu state. This is simple strain and when displacements are measured at the borehole wall is termed cavity strain, ε_c.

R_0 can be approximated by the at rest radius of the instrument. The preferred approach is to identify when the applied pressure has reached the insitu lateral stress, and interpolate from this the corresponding radius, which then becomes R_0.

Note that although the pressuremeter measures the radius of the cavity wall, ε_c is actually a specific instance of circumferential or hoop strain. It is usually expressed as a percentage.

Figure 1.2 shows how pressures and strains in the expanding borehole are defined.

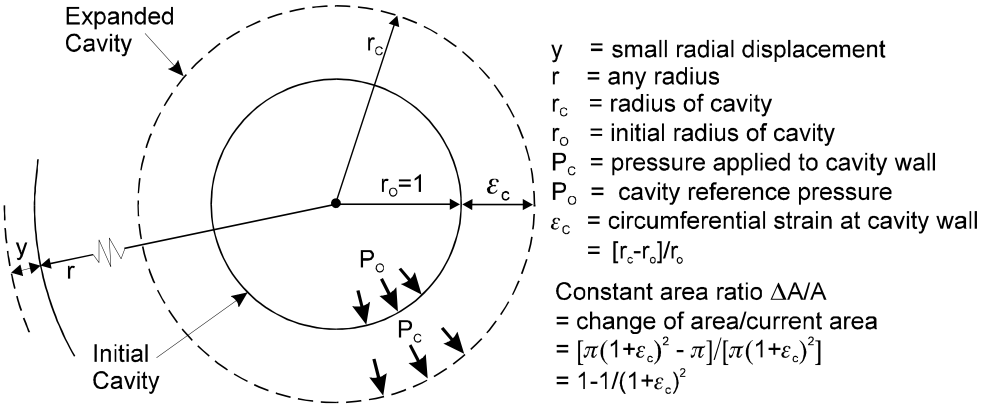


Fig 1.2 Pressures and strains around the expanding cavity

The other strain commonly used is the constant area ratio, which is shear strain. As fig 1.2 indicates it can be defined in terms of simple strain.

1.3 Average displacements versus the output of the separate axes

There are a number of displacement sensors in the expansion probe but recommended practice is to quote parameters from the average displacement curve. This is for two reasons:

- The reference for the measured displacements is the body of the instrument itself - trying to separate the individual axes means assuming that the body of the instrument remains fixed at all times, which is not realistic.

- All available analyses assume isotropic properties in the surrounding soil, and only the average pressure/strain curve represents this condition.

These remarks assume that the instrument is in full working order throughout the test - failure of a displacement follower means that alternative strategies must be adopted.

The significance of the first point above has been demonstrated by an examination of cycles of unloading taken from separate arms (Whittle 1993) and by work with a six arm version of the SBP (Whittle et al 1995). In the case of the 3 arm SBP an exception is sometimes made for the initial part of the loading prior to yield. In such circumstances the response of the separate arms may yield clues to the initial stress state in the surrounding soil, allowing an assessment of the degree of insertion disturbance.

1.4 The analysis program

We use (and supply to others) software for analysing a pressuremeter test. The program is called **WINSITU,** it has been in use for a number of years.

To use the program the user must first read in a text file of test data in engineering units. The program needs to know the type of instrument being used, and the user may choose to enter additional background information about the test.

The next task is to identify for the program the nature of the individual data points. Broadly, the options are these:

- a point can be part of the expansion curve
- or part of a reload loop
- or part of the contraction curve
- or none of the above. This might mean a ‘rogue’ data point, but it is more likely to be true of parts of the loading where the expansion was slowed prior to taking an unload/reload cycle. Data points recorded at this time are neither part of the expansion nor part of a cycle, and should be identified as such.

There is a quick on-screen routine for marking the points. Once marked, they appear in different colours. Most of the analyses use a limited set of the available data - for example the Gibson & Anderson analysis for undrained shear strength uses only points on the expansion curve.

The program implements all the standard analyses mainly in a graphical form. As fig 1.1 implies, there are significant changes of gradient in the pressure/strain curve denoting critical soil parameters. The user of the program is provided with on-screen tools to mark these breakpoints or to obtain the slope of the loading curve. The tools can be visualised as rulers, whose position is stored by the program in the file of test data. The evidence for any derived parameter is a screen dump of the appropriate analysis that shows the position of any rulers set by the user and quotes the parameter obtained.

Even when the user declines to make a choice it is good practice to provide the screen dump as evidence of why a choice is difficult.

The results for a test appear as a summary sheet of derived parameters followed by a number of plots showing the application of the various procedures.

Sometimes analyses are required which are not included in the WINSITU program. In such instances commonly available spreadsheet software is used to implement the new analysis. Inevitably in such circumstances there is some risk of human error affecting the conversion of data in engineering units to the form required for analysis. WINSITU has export facilities and wherever possible is used as the data source for the spreadsheet.

2 Analyses for Insitu Lateral Stress

2.1 Overview

The expansion pressuremeter test is a sequence of measured co-ordinates of pressure and displacement of the cavity wall (once suitable corrections have been made to compensate for the response of the elastic membrane).

In order to solve the boundary problem, an origin for the expansion has to be determined. For insertion methods that imply stress *relief*, the origin is taken to be the point where insitu conditions are restored to the cavity. This means that an estimate of the insitu lateral stress has to be made, and the measured radius of the cavity at the point where the insitu lateral stress is restored is used to convert subsequent displacements to strain.

For an SBP it is possible to recognise the insitu lateral stress by inspection, the so-called lift-off method. It is also possible to recognise by inspection the shear stress limit (the point marked p_f in fig 1.1) as this is indicated by the onset of a markedly non-linear response. An iterative procedure first suggested by Marsland & Randolph (1977) allows the insitu lateral stress to be inferred. The method is not valid for tests in sands and tests in material with non-linear elastic properties. This effectively rules out all soils. Nevertheless it is usual to run the analysis because it tends to set an upper limit to any estimate of insitu lateral stress.

Both methods are outlined by Mair & Wood (1987). Note that these methods amount to obtaining a value for the cavity reference pressure, p_o. It is impossible to measure the insitu lateral stress σ_{ho} because the act of placing instrumentation always results in some disturbance, even if small. The methods above are indirect indicators for determining σ_{ho}. It is open to question whether the reference stress is equivalent to the insitu lateral stress, and it is usual to bring a range of evidence to bear in order to decide if a particular value for p_o is also a plausible value for σ_{ho} . External evidence might take the form of using the derived reference stress within a k_O calculation, or checking that the derived vertical/horizontal anisotropy can be supported by the material shear strength i.e.

$$\sigma_{ho} - \sigma_{vo} < 2C_u \, . \qquad \text{...[Equ.2.1]}$$

A more complex approach uses the full set of parameters derived from a pressuremeter test within a model, and discovers whether the measured field curve can be recovered. The input data set is then adjusted in a strictly controlled manner until the best match for all parameters is obtained.

2.2 Lift-off

This method is applicable only to the SBP. In principle it is a straightforward procedure. The instrument is assumed to be bored into the ground with insignificant disturbance caused to the surrounding material. If the insitu conditions around the instrument remain unchanged by the insertion process then the pressure at which the membrane first moves and the cavity begins to expand is p_o. The corresponding cavity diameter will be the same as the at rest diameter of the instrument. Because the initial part of a SBP test is very stiff the choice is made from an enlarged view of the first 0.2mm (0.5% strain) of the expansion.

Difficulties arise because the instrument has a finite stiffness and hence there is instrument compliance to be separated from the expansion of the cavity. In addition the instrument is being externally loaded by the lateral stress when the test is started. This external stress tends to deflect the arms of the instrument and reveals any imperfections in the seating of the arms.

The imperfections, in effect small movements, are revealed when the pressure differential across the membrane is removed, i.e. exactly at the point where the cavity reference pressure is reached.

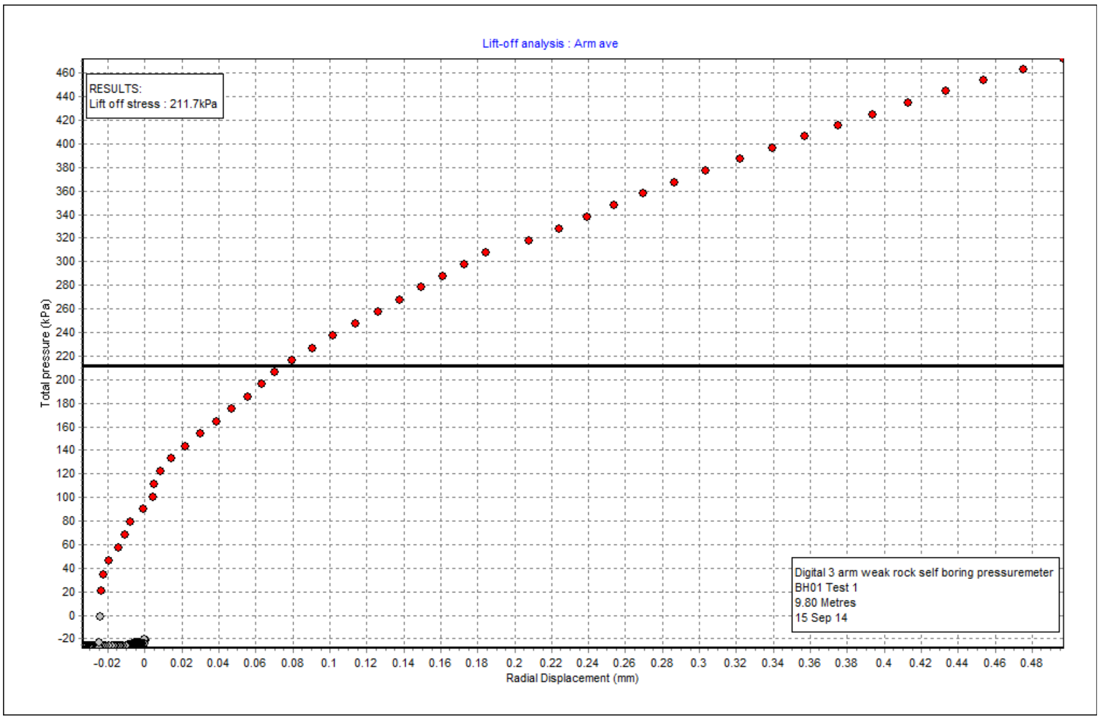


Fig 2.1 An example of lift-off

In a simplistic approach these arm 'signatures' could be considered as positive indications of the reference pressure. However in the ground it is not possible to have displacements without an associated change in stress, which add to or subtract from the reference pressure.

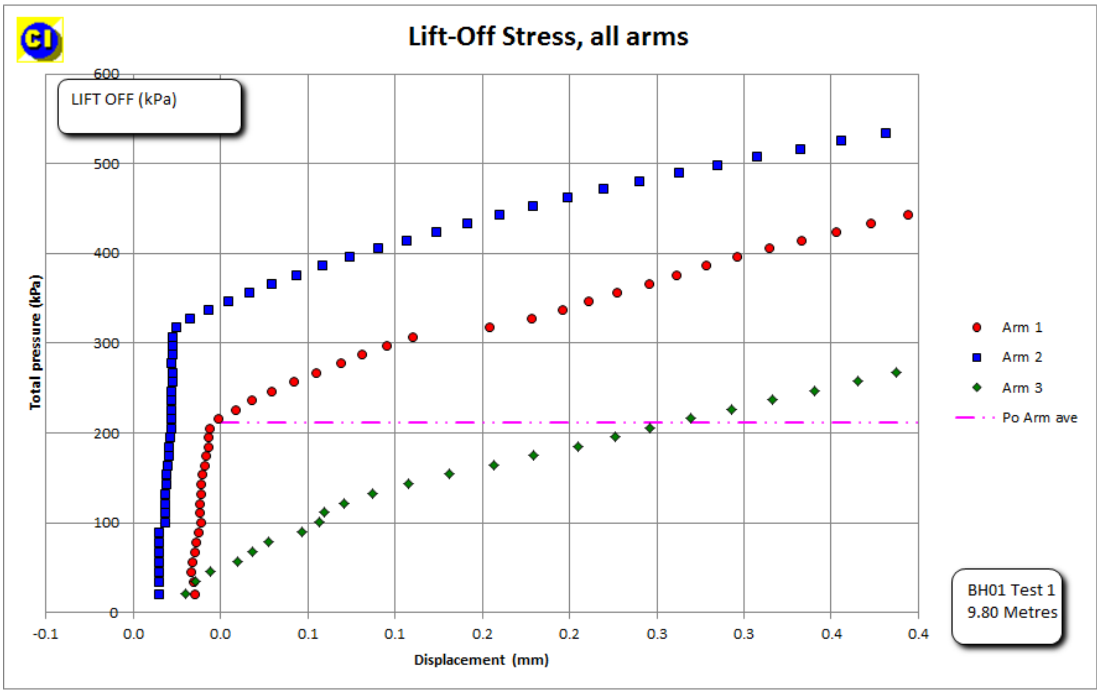


Fig 2.2 Lift-off, all arms shown

As a result of finite instrument stiffness and small movements from the displacement sensors applying the lift-off analysis means that there is much uncertainty attached to identifying a plausible reference pressure. Conventional practice for coping with this uncertainty is to relax the definition of 'lift-off' to mean something more like 'significant movement'.

Figure 2.2 is a typical illustration of the problems involved with identifying lift-off. Here the individual arms from a SBP test are plotted together, fig 2.1 being the average output of these arms. There are a choice of lift-off points corresponding to a rigorous interpretation of what is implied by the term. In general the average lift-off is similar to that obtained from the first arm to move and sometimes small movements seen in separate arms cancel out in the average view. The difference one side of the probe to the other suggests that the probe may not be installed perfectly vertically, and cancelled movement show the influence of instrument compliance.

It is important to bear in mind the scale. All the lift-off information is concentrated into the first 100 microns of the expansion or about 0.25% cavity strain. In this test the elastic strain range is at least 1.0% cavity strain. Because the movements are well within the elastic range of the material the analyst is justified in attributing significance to the output of the separate arms. In this event the arithmetic mean of the separate lift-off points is often a more useful parameter than lift-off derived from averaged arm displacement data.

If the strict definition of 'lift-off' could be applied then no assumptions concerning soil response are required. Accepting that some movement takes place prior to ‘lift-off’ implies that assumptions be made about the mode of deformation. In the less rigorous application of 'lift-off' it is important that the analyst identifies the onset of plastic behaviour as a guide to deciding that some conspicuous change of form in the loading curve at a lesser stress is likely to be p_o. Our plots would still refer to such a break point as 'lift-off' but clearly it is something else, p_o by inspection perhaps.

2.3 Marsland & Randolph (1977) Analysis

Marsland & Randolph analysis relies on being able to identify the onset of plastic behaviour, the yield stress p_f. The argument is as follows:

- In the vicinity of the insitu lateral stress the soil response is simple elastic manner and therefore the total pressure/ cavity strain plot will be linear
- Elastic behaviour will cease when the undrained shear strength of the soil is reached in the wall of the cavity, and hence the pressure /strain plot will begin to curve (see Fig 1.1).
- This can be expressed as: $p_f = p_o + c_u$ .....[2.2]
- From this it follows that p_o can be deduced by iteration. Initially a guess is made of a value for p_o; using this guess to define a temporary strain origin a total pressure:log volumetric strain plot is then generated in order to derive a value for c_u. The sum of these two parameters is compared with the selected value of p_f. The choice of p_o is then suitably adjusted and the process repeated until a match is found. It is a straightforward matter to carry out this procedure on the computer.

The modified method in current use is a response to the difficulty that perfectly plastic deformation is not a realistic enough model for many materials and yield may occur at a different shear stress than the large strain shear strength. Hawkins et al (1990) suggested that the most appropriate choice was that value of shear stress pertaining at the apparent onset of plasticity, so equ. [2.2] now becomes:

$$p_f = p_o + \tau_f \qquad .....[2.3]$$

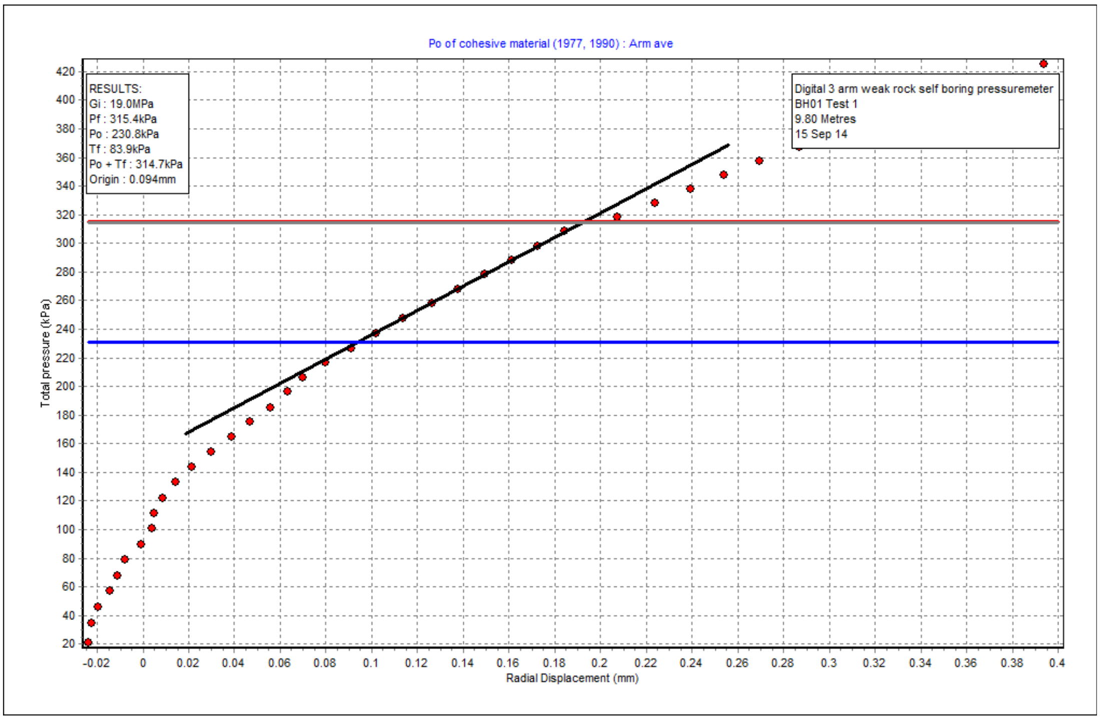


Fig 2.3 An example of the Marsland & Randolph analysis

τ_f can be obtained from a total pressure:log volumetric strain plot by selecting the slope at the pressure and strain corresponding to the choice of p_f (in practice, using the Palmer (1972) argument to identify the mobilised shear stress at failure).

The analysis is implemented graphically, using a number of rulers to identify significant points on the curve (Fig 2.3).

There are a number of problems:

- There can a choice of slopes for G_i , giving multiple possibilities for p_f . In practice the first slope encountered is usually too stiff to make a credible choice for G_i and is probably an indication of insertion disturbance.
- The assumption of simple elastic response - in practice most soils exhibit marked non-linear elastic characteristics, so that the pressure at which the material appears to go fully plastic is more than one increment of shear strength above P_0 - this point is developed later.
- The original analysis was developed as an aid to the interpretation of pre-bored pressuremeter tests where the process of forming the pocket results in the complete unloading of the cavity prior to the test commencing. It is certain therefore that the soil has seen stress relief. It is arguable whether in these circumstances that the yield point remains unchanged, as more than elastic unloading has taken place. However the form of such tests does tend to give an unambiguous choice for the onset of plasticity.

- In a soft ground self bored pressuremeter test the situation is not so clear cut. The very factors that make the test desirable also results in more realistic behaviour being seen in the form of the early part of the test, with non-linear elasticity being a feature. Hence a choice of p_f is by no means easy. In general the better the test the harder such a choice becomes. However it is probable that in a good test the lift off pressure would be a credible choice so that in the wider context it is not a serious problem.
- A disturbed SBP test does not necessarily imply stress relief. Typically disturbance arises out of damage to the shoe cutting edge; if the shoe is enlarged then stress relief will result. However if the shoe is damaged in such a way that it cuts undersize or becomes blocked (even momentarily) then stress increase will take place and plasticity will be masked by a rise in the pore water pressures around the instrument. In this event the analysis can contribute nothing – forcing such data to fit the assumptions of the analysis will over-estimate the insitu lateral stress.

Against these objections there is good empirical evidence that no matter the mode of failure, identifying the yield stress and working back to the insitu stress works for all soils, provided one takes the apparent mobilized shear stress at failure, not large strain. For this reason the procedure is often applied with apparent success to tests in frictional material.

2.4 Deriving insitu lateral stress by synthesis

The doubt concerning the appropriateness of using the measured values for cavity reference pressure p_o as best estimates for the insitu lateral stress σ_{ho} mean that other methods for inferring plausible values are required. Jefferies (1988) is a procedure for deriving insitu lateral stress, stiffness and strength from undrained pressuremeter curves by matching the measured data points with an iteratively selected set of numbers. Some rigour is introduced into the procedure by making the single set of parameters match the contraction as well as the expansion phases of the SBPM test.

For the procedure to work the model used to represent the deformation characteristics of the soil has to be realistic. Jefferies (1988) assumes a simple elastic/perfectly plastic shear stress:shear strain response. Outside of a computer there is no such soil and despite the claims made for it, the procedure fails – in particular it cannot predict the measured field values for stiffness, the one property of the soil pressuremeters can provide without major difficulty.

However the procedure can be used with more realistic soil models, and it is customary now to back-analyse undrained tests using a non-linear elastic/perfectly plastic shear stress:shear strain solution. This uses measured values of stiffness and shear strength so the only variable to be decided is the insitu lateral stress. Both expansion and contraction phases of the test are fitted (Fig 2.4).

For a SBP arranged to drill to size the values for lateral stress derived using this procedure are often lower than those obtained by inspection, and are consistent with a view of the test as slightly under drilled, raising the state of stress around the probe. If as in the case of these tests the probe is configured to drill fractionally oversize the reverse situation applies. The procedure can also be applied to pre-bored pressuremeter test data but the fit to the loading will always be questionable.

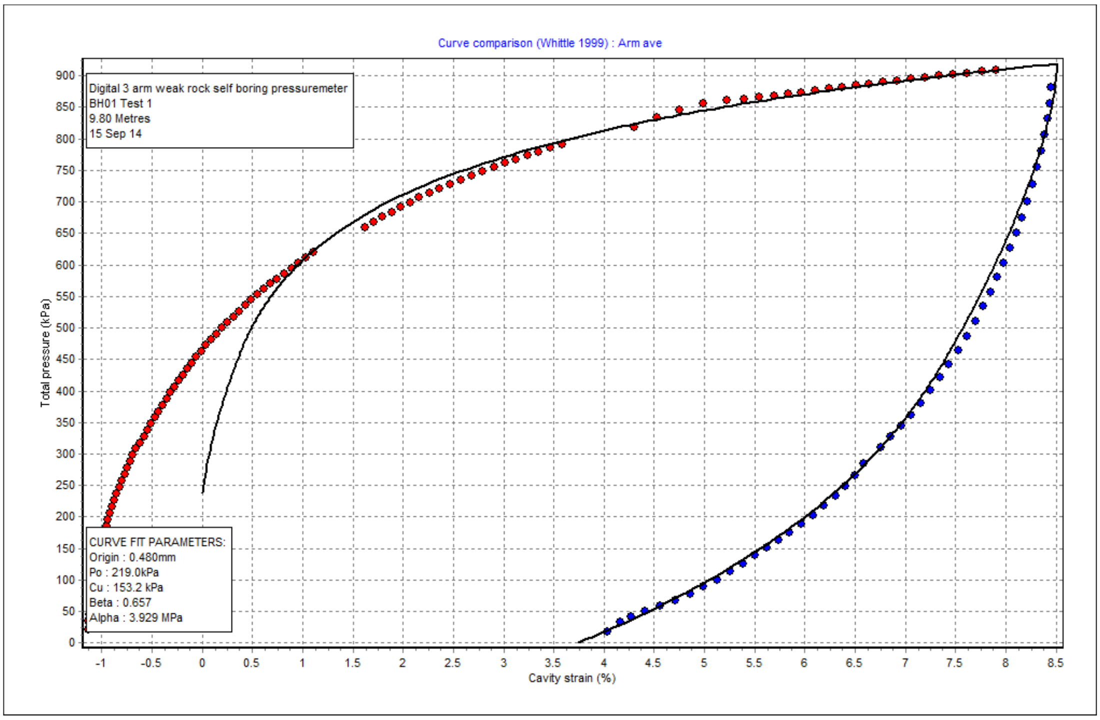


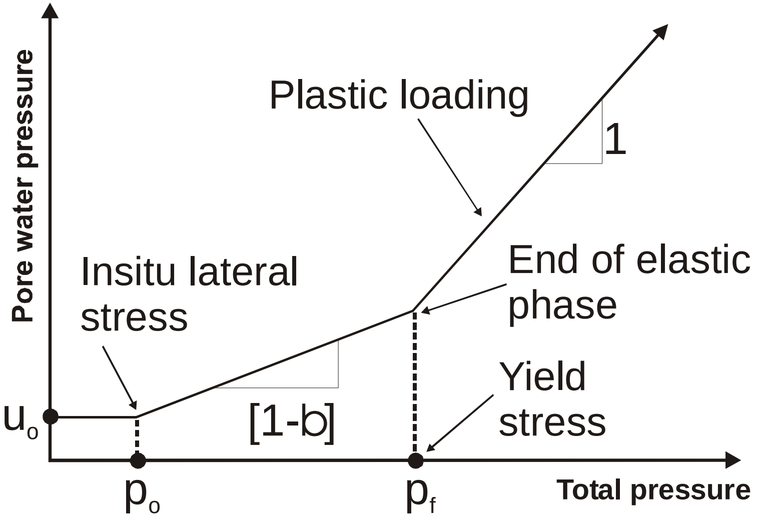
Fig 2.4 Using an undrained non-linear elastic/perfectly plastic solution

Note that it is only possible to derive one value for insitu lateral stress using these procedures, as isotropy of soil properties is a fundamental assumption. Because the procedure makes uses of all the evidence it is the preferred method for deriving the insitu lateral stress. However the nature of the material on this contract was such that even the supposed undrained tests indicated a lack of excess pore pressure, so that in the example above it has been necessary to ignore the final part of the loading curve. This of course makes the result open to question.

2.5 Deriving parameters from the excess pore pressure trend

Bolton & Whittle (1999) predict the trend of excess pore water build –up from an undrained cavity expansion in a non-linear elastic/perfectly plastic material (Fig 2.5**).** The significant difference between this trend and that in a simple elastic/perfectly plastic medium is the generation of some excess pore pressure during the elastic phase of the test prior to the material fully yielding. The rate at which the pore pressure rises during the elastic phase is related to the exponent of non-linearity, β, a number less than 1 unless the response is truly linear elastic (the Bolton & Whittle analysis is described more fully later in this Appendix). In both cases, once the material becomes plastic, there is a 1 for 1 correspondence between changes in total stress and changes in pore water pressure.

Fig 2.5 **The ideal pore pressure response (after Bolton & Whittle, 1999)**



In practice very few self boring tests have the necessary minimal disturbance to show the full theoretical curve, and even if they do so then interruptions to the loading to take unload/reload cycles tend to disrupt the plastic response. It is sometimes possible to recognise a partial set of the parameters predicted in fig 2.5.

Fig 2.6 An example of pore pressure response

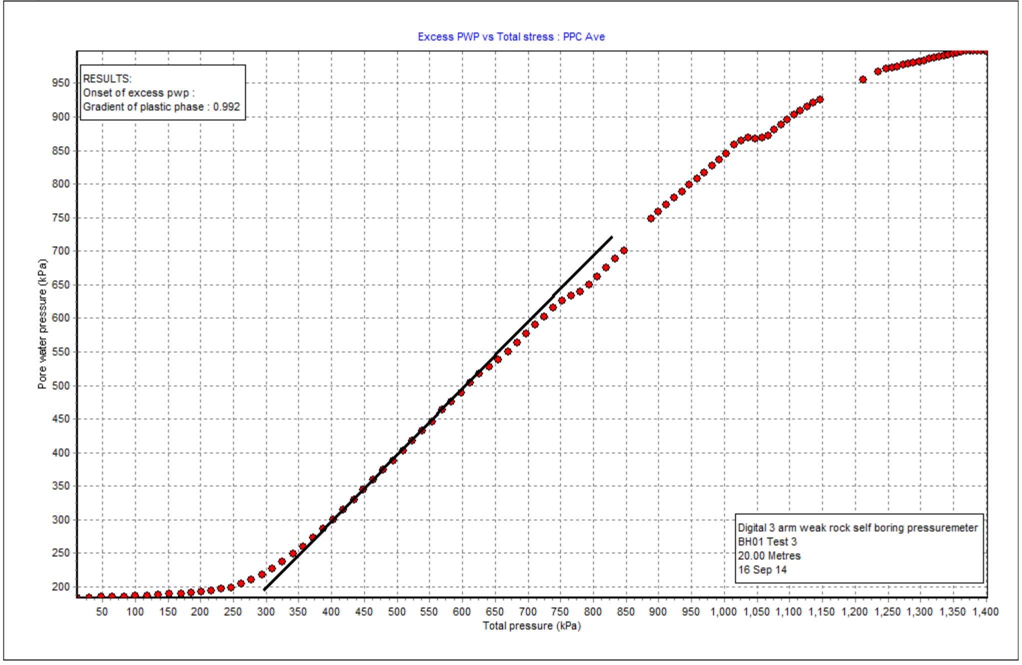


Figure 2.6 is an example. The gradient of the plastic phase is close to the predicted 1 for an undrained expansion but yield and the pseudo-elastic response are not clearly delineated. Later in the test when unload/reload cycles are taken the pore water pressure response tends to level off. This indicates partial drainage, not necessarily in the soil mass but locally at the borehole wall where gaps in the protective sheath introduce axial drainage paths.

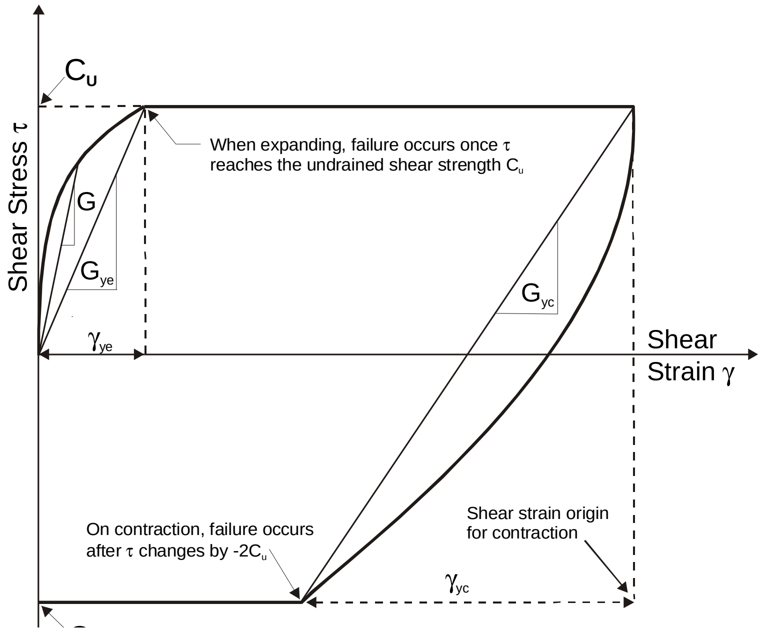
3 Analyses for undrained shear strength (C_u)

Once the origin is known, the expansion and contraction phases of the test can be used to determine the material shear strength. Two methods have been applied:

Case A

Assume the shape of the shear strength:shear strain curve and hence derive a closed form solution for the pressuremeter curve. For the SBPM tests on this contract a non-linear elastic/perfectly plastic soil response has been assumed. This has been solved (Bolton & Whittle 1999) for the case where the non-linear elastic characteristics are given by a power law. Strictly, the form of the elastic phase is of no consequence for the derivation of shear strength once perfect plasticity is assumed, and the classic procedure developed by Gibson & Anderson (1961) could be used. For both solutions the slope of the pressure /strain curve plotted on semilog axes gives the shear strength directly and an estimate of the ultimate limit pressure. However the terminology of the non-linear elastic solution is different from the linear elastic model and this avoids some conceptual problems.

Fig 3.1 Non-linear elastic/Perfectly plastic shear stress : strain curve



Case B

Make no assumptions about the shape of the shear stress:shear strain curve but differentiate the measured pressuremeter curve directly to give the shear stress response. Palmer (1972) gives the differential equation used to describe the complete shear stress:shear strain response of a material deforming under undrained conditions. The equation can be solved graphically or numerically by taking the current tangent of the total pressure/cavity strain plot, but the success of the method depends on the smoothness of the measured data.

3.1 Bolton & Whittle (1999)

Figure 3.1 gives the shear stress: shear strain response of a non-linear elastic/perfectly plastic soil. Both expansion and contraction are included. Because this solution is not widely known it is given in greater depth here than is strictly necessary.

Assume that the non-linear elastic response of soils can be fitted with a power law of the form

$$\tau = \alpha\gamma^{\beta} \qquad \text{...[Equ. 3.1]}$$

This assumption will be justified later by inspecting unload/reload cycles.

Around the pressuremeter, assume that the soil is deformed under conditions of axial symmetry and the expansion is undrained. The following relationships apply (see fig 1.2 for an explanation of the symbols used):

Axial strain $\varepsilon_a = 0$

Circumferential strain $\varepsilon_\theta = -\rho/r$.

The expansion is undrained so radial strain $\varepsilon_r = -\varepsilon_\theta = \rho/r$

Shear strain $\gamma = \varepsilon_\theta + \varepsilon_r = 2\rho/r = \delta A/A$

The equation of radial equilibrium applies throughout the expansion:

$$r\frac{d\sigma_r}{dr} + (\sigma_r - \sigma_\theta) = 0 \qquad \text{... [Equ. 3.2]}$$

where σ_r is radial stress and σ_θ is circumferential stress.

Using τ to represent the maximum shear stress, equation [3.2] becomes:

$$r\frac{d\sigma_r}{dr} + 2\tau = 0 \qquad \text{... [Equ.3.3]}$$

Now using the constitutive relationship $\tau = \alpha\gamma^{\beta}$ and writing the current area in terms of radius:

$$\frac{d\sigma_r}{dr} + \frac{2a}{r}\left(\frac{\delta A}{\pi r^2}\right)^{\beta} = 0 \qquad \text{... [Equ. 3.4]}$$

Noting that $(1/r)(1/r^2)^{\beta} = r^{-(2\beta+1)}$:

$$\frac{d\sigma_r}{dr} + 2a\left(\frac{\delta A}{\pi}\right)^{\beta} r^{-(2\beta+1)} = 0 \qquad \text{... [Equ. 3.5]}$$

and integrating between the reference state, and the pressure and radius at the cavity wall:

$$\int_{Po}^{P} \sigma_r = -2a\left(\frac{\delta A}{\pi}\right)^{\beta} \int_{\infty}^{r_C} r^{-(2\beta+1)} dr \qquad \text{... [Equ. 3.6]}$$

so

$$p - p_o = 2a\left(\frac{\delta A}{\pi}\right)^{\beta}\left(\frac{1}{r^2}\right)^{\beta}\left(\frac{1}{2\beta}\right) = \frac{a}{\beta}\left(\frac{\delta A}{A}\right)^{\beta} \qquad \text{... [Equ. 3.7]}$$

The right hand side of this result is the shear stress mobilised at the cavity wall and can be written as τ_C/β. Note that if $\beta = 1$, the condition for linear elastic response, the right hand side of equation [3.7] reverts to the following familiar expression where α is shear modulus G:

$$\alpha[\delta A / A] \qquad \text{... [Equ. 3.8]}$$

The end of the elastic phase is reached when $\tau_C = c_u$ for the expansion, hence

$$p - p_O = c_u/\beta \qquad \text{... [Equ. 3.9]}$$

Thereafter, there is a plastic zone confined by the limiting elastic radial stress of c_u/β. Equation [3.2] still applies, so

$$r\frac{d\sigma_r}{dr} + 2c_u = 0 \qquad \text{... [Equ. 3.10]}$$

This gives

$$d\sigma_r = -2c_u \frac{dr}{r} \qquad \text{... [Equ.3.11]}$$

Integrating between the radii of the cavity wall and of the elastic-plastic transition:

$$\int_{P_C}^{P_O + \frac{c_u}{\beta}} d\sigma_r = -2c_u \int_{r_C}^{r_Y} \frac{dr}{r}$$

Hence

$$p_C = p_O + c_u \left[\frac{1}{\beta} + \ln\left(\frac{r_y^2}{r_c^2} \right) \right] \qquad \text{... [Equ.3.12]}$$

In a soil being sheared at constant specific volume $\frac{r_y^2}{r_c^2} = \frac{\gamma_{ye}}{\gamma_{ce}}$ (Gibson & Anderson 1961) the ratio of the shear strain required to initiate plasticity during expansion γ_{ye} to the shear strain at the cavity wall during expansion γ_{ce}. This leads to

$$p_C = p_O + c_u \left[\frac{1}{\beta} - \ln(\gamma_{ye}) + \ln(\gamma_{ce}) \right] \qquad \text{... [Equ.3.13]}$$

This result resembles the simple elastic/perfectly plastic solution proposed by Gibson & Anderson. For the special case of a simple elastic response when β=1 the two solutions are identical. Indefinite expansion of the borehole is predicted by:

$$p_{Limit} = p_O + c_u \left[\frac{1}{\beta} - Ln(\gamma_{ye}) \right] \qquad \text{... [Equ. 3.14]}$$

and substituting this into equation [3.13] gives

$$p_c = p_{Limit} + c_u \, \mathrm{Ln}(\gamma_{ce}) \qquad \text{... [Equ. 3.15]}$$

showing the undrained shear strength and limit pressure can be obtained from the gradient and intercept of a plot of total pressure at the cavity wall versus the natural log of the current cavity shear strain (Fig D. 8).

Note that equation [3.13] makes no explicit reference to shear modulus.

3.2 Analysing pressuremeter undrained contraction data

The expansion phase ends at some value of pressure and cavity strain at the borehole wall p_{max} and ε_{cmax}. This is the origin for the contraction event. During contraction, the end of the elastic phase is reached when $\tau_C = -2\ c_u$, hence

$$p_{max} - p = 2c_u/\beta \qquad \text{... [Equ. 3.16]}$$

Fig 3.2 Deriving c_u from expansion data

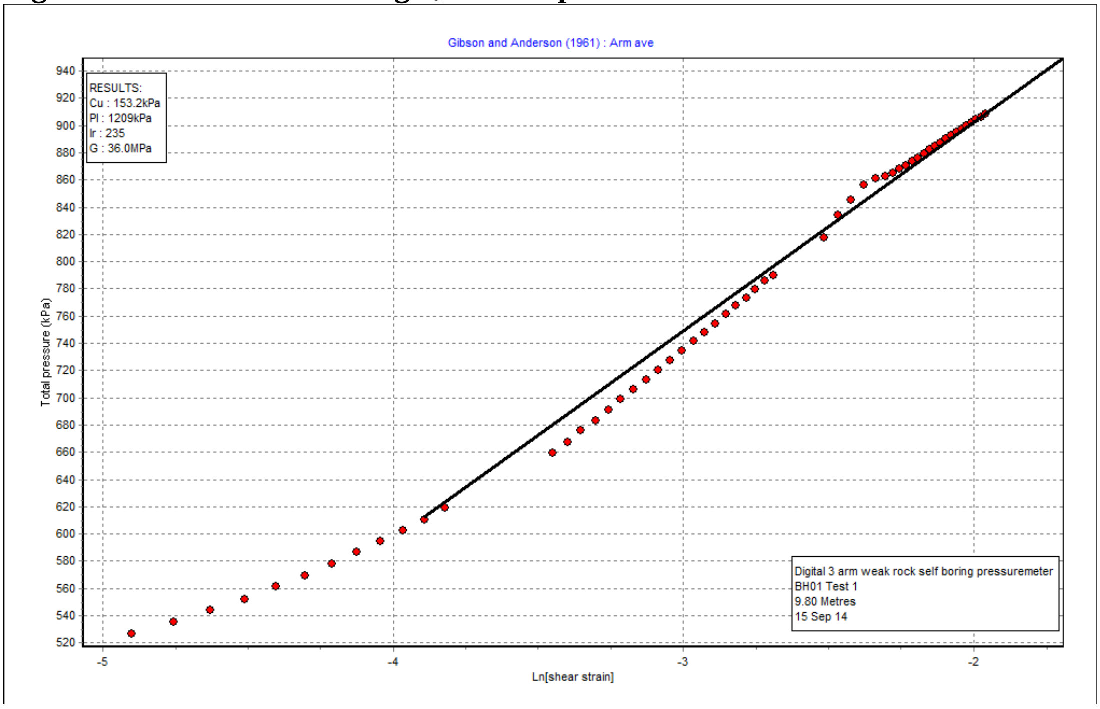
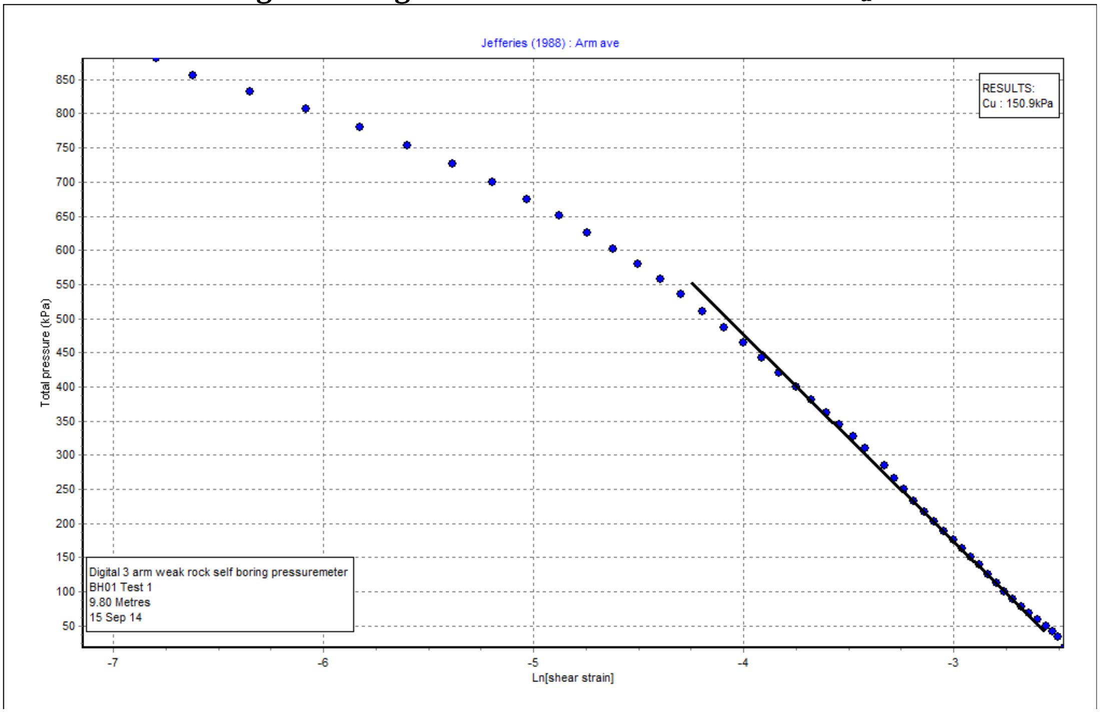


Fig 3.3 Using the contraction curve to derive c_u



Jefferies (1988) gives the simple elastic solution for the relationship between pressures and strains at the cavity wall once reverse plastic failure is initiated:

$$p = p_{max} - 2c_u[1+\mathrm{Ln}(\gamma_{cc})-\mathrm{Ln}(2\gamma_{ye})] \qquad \text{... [Equ. 3.17]}$$

This is not quite as his solution is written - γ_{cc} is the shear strain at the cavity wall during contraction (see equation 22 below) and γ_{ye} is the shear strain required to initiate yielding when expanding the cavity. From [3.13] it follows the non-linear elastic version of [3.17] is given by

$$p = p_{max} - 2c_u[(1/\beta) + Ln(\gamma_{cc}) - Ln(2\gamma_{ye}/\beta)] \qquad \text{... [Equ. 3.18]}$$

Shear strain γ_{cc} is obtained from conventional cavity strain ε_c by:

$$[(1+\varepsilon_{cmax})/(1+\varepsilon_c)] - [(1+\varepsilon_c)/(1+\varepsilon_{cmax})] \qquad \text{... [Equ. 3.19]}$$

An inspection of equation [3.19] indicates that a plot of the natural log of the contraction shear strain against total pressure at the cavity wall gives a curve whose ultimate gradient is –2c_u. Fig 3.3 gives an example for the contraction phase. As before, if $\beta = 1$, the condition for simple elastic response, all non-linear elastic equations given above revert to published solutions for simple elastic/perfectly plastic material.

Sometimes there is uncertainty in deciding the ultimate slope in both the expansion and contraction examples. For the expansion there can be indications of shear strength changing after the point in loading where unload/reload loops have been taken. It is assumed here that the taking of the cycles has allowed partial drainage, invalidating the primary assumption underpinning the analysis. For the contraction there is a difficulty in that the slope sometimes increases sharply towards the end -the start of this seems to coincide with the point where the major and minor stresses reverse.

One good reason for using contraction data to discover the shear strength is the certainty of knowing the origin for the contraction event. Altering the length of the strain scale for the expansion event has a noticeable impact on the derived shear strength. All things being equal, a comparison between loading and unloading values may indicate insertion disturbance but also a means for correcting for it.

3.3 Palmer (1972)

The Palmer analysis is an example of more information being obtained from the pressuremeter test if fewer assumptions are made. The analysis shows that the pressure:strain graph is the integrated shear stress:shear strain curve. Taking the slope of the pressure:strain graph at any point gives the mobilised shear stress directly, and allows the complete shear stress:shear strain curve to be plotted. In terms of cavity strain the shear stress τ is:

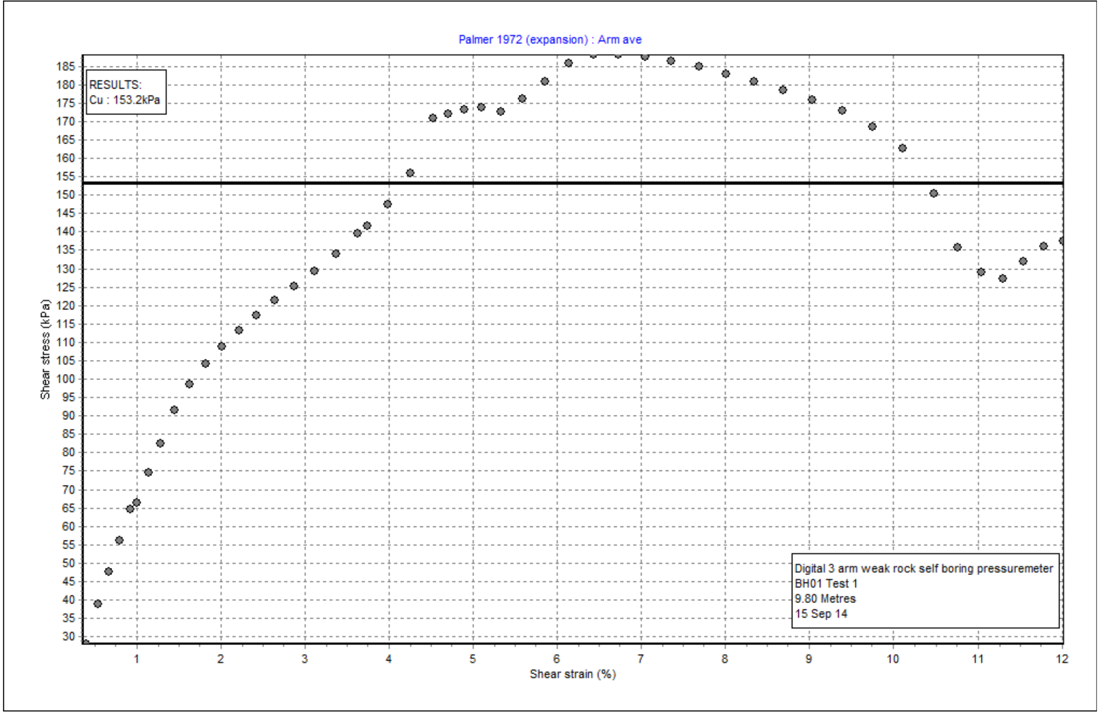
$$\tau = \tfrac{1}{2}\varepsilon_c(1+\varepsilon_c)(2+\varepsilon_c)dp/d\varepsilon_c \qquad \text{... [Equ.3.20]}$$

More conveniently, perhaps, equation [3.20] can also be written in terms of volumetric strain as:

$$\tau = dp/d[\ln(\Delta A/A)] \qquad \text{... [Equ.3.21]}$$

This implies that the gradient at any point on the semilog plot used for the perfectly plastic analysis gives the mobilised shear stress directly. The examples shown are from a test in clay.

Fig 3.4 An example of the Palmer (1972) analysis



The analysis is awkward to implement on the computer because the differentiation process highlights any irregularities in the data. This is especially irritating because the stress strain response must be a smooth curve. Possible strategies involve curve fitting the measured data prior to applying the solution, but this is a mistake. Minor changes of gradient on the loading path are usually not random, but a response to some event such as the taking of an unload/reload cycle.

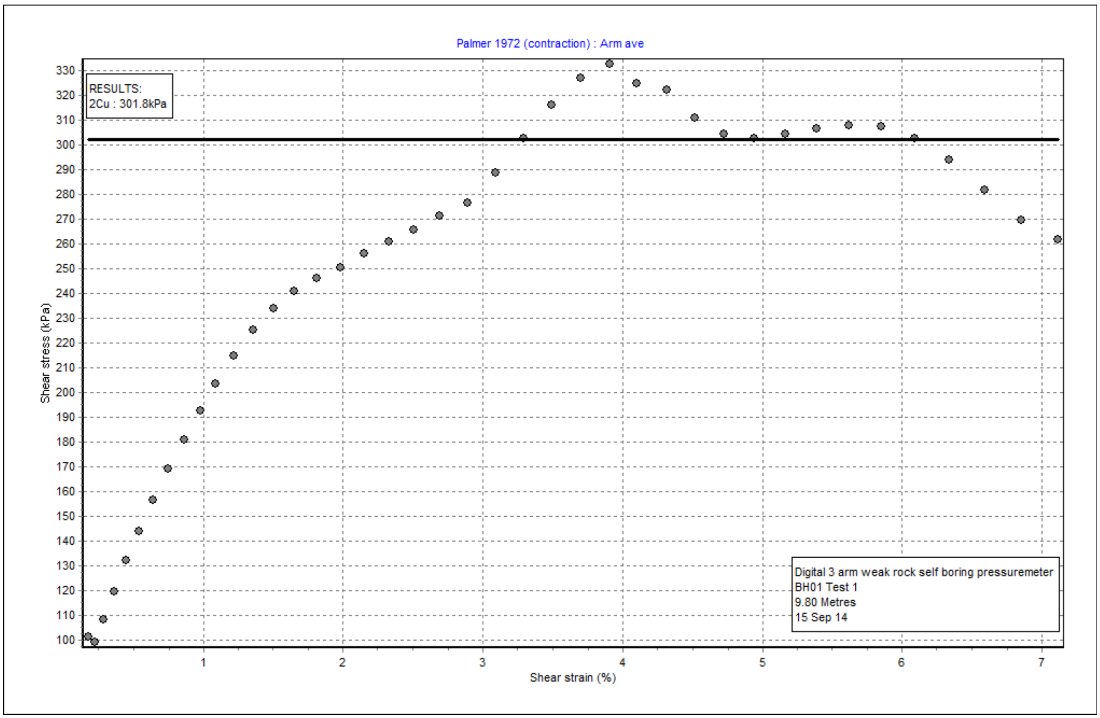


Fig 3.5 **P**almer (1972) analysis applied to contraction data

If there are clear indications of peak and residual shear strength then horizontal rulers are available to mark these values. The plot gives a 'map' of the shear stress, and it is the form of the complete curve that is of interest. The analysis is very sensitive to insertion disturbance - in particular insufficient allowance for stress relief will give an apparent peak in the stress/strain response. It is also possible that the peak is a rate effect – considered from the perspective of the elastic/plastic boundary, the standard strain rate of 1% per minute at the cavity wall gives an equivalent rate of about 70% per minute for this clay immediately following first yield.

Because the origin for the contraction event is more or less known, applying the subtangent analysis to the unloading of the cavity usually gives a better result than the loading.

4 Shear Modulus

Terms:

G_P	Pressuremeter shear modulus
G_S	Secant shear modulus
G_T	Tangential shear modulus
G_{100}	Secant shear modulus at the maximum elastic shear strain
$G_{HH,}$ G_{VH}	Shear moduli for transversely isotropic material
E_H, E_V	Young's modulus in the horizontal and vertical direction
ν_{HH}, ν_{HV}	Poisson's ratios for transversely isotropic material
n	Ratio of horizontal to vertical Young's modulus E_H/E_V
K_O	Ratio of horizontal to vertical effective insitu stress
τ	Shear stress
p_C	Pressure measured at the cavity wall
ε_c	Circumferential strain measured at the borehole wall
γ	Shear strain
γ_c	Shear strain measured at the borehole wall
γ_s	Invariant shear strain
η	Radial stress intercept
β	Elastic exponent
α	Shear stress intercept

4.1 Background

Values of stiffness in real soils however measured are strain level and stress level dependent. Pressuremeter stiffness is affected by the additional factor of cross anisotropy. The pressuremeter used conventionally gives shear modulus parameters of type G_{HH}, where the first suffix shows the direction of loading and the second suffix the direction of particle movement. Most design calculations that require a value for shear modulus mean in practice the independent shear modulus $G_{VH.}$ Translating between pressuremeter values and alternative expressions for modulus is complex but worth pursuing because of the high quality of the pressuremeter measure. What follows is a brief outline of a possible approach.

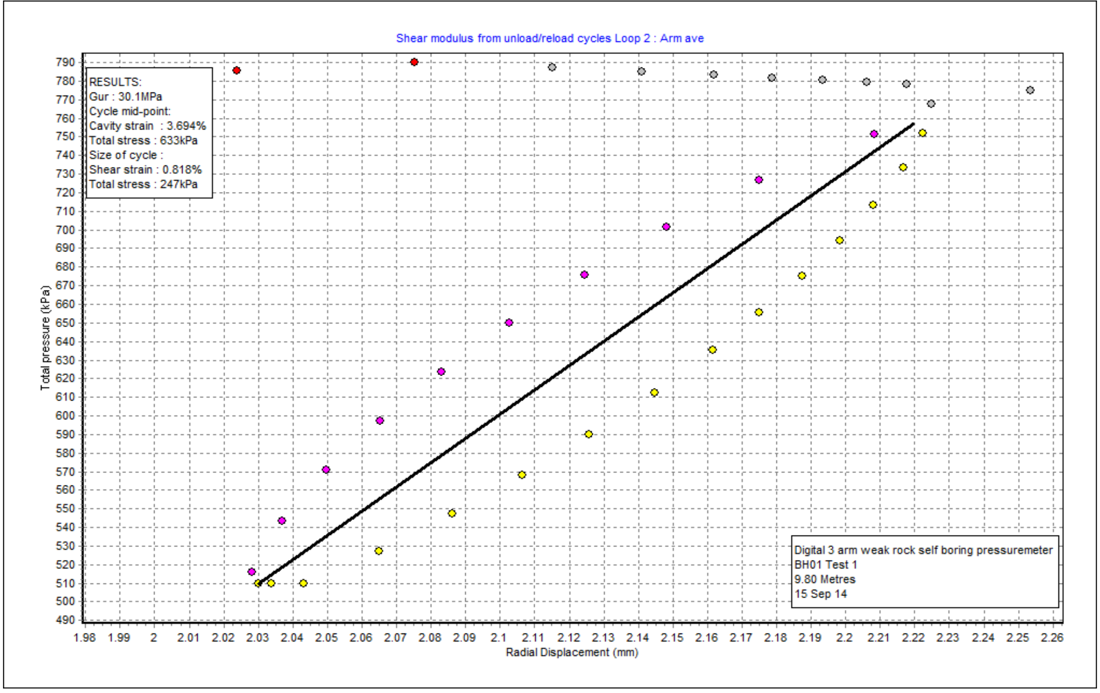
Cycles of unloading and reloading loops are the primary source for shear modulus data. *If* the material was linear elastic then the slope of a line bisecting the apices of the loop can be used to derive the shear modulus. Figure D.12 shows a typical example of one such cycle. The equation used is:

$$G = [1+\varepsilon_c][\Delta p_c/2\Delta\varepsilon_c] \quad \text{... [Equ.4.1]}$$

Implicit in this equation is the assumption that Δp_c is equivalent to $\Delta\tau_c$, that is to say the material has linear elastic characteristics.

In addition, the program carries out a regression analysis of the data points that are part of the reload loop. If the loop is good, that is symmetrical and without indications of scatter, then the two values of modulus obtained will be the same. However the regression analysis is sensitive to misplaced data points, which the visual technique can ignore.

Fig 4.1 Expanded view of an unload/reload cycle



It is important that the effects of creep (for whatever cause) be minimised before starting the cycle, so it is usual to hold the pressure in the probe for a short time (maybe as little as a minute) prior to starting to unload.

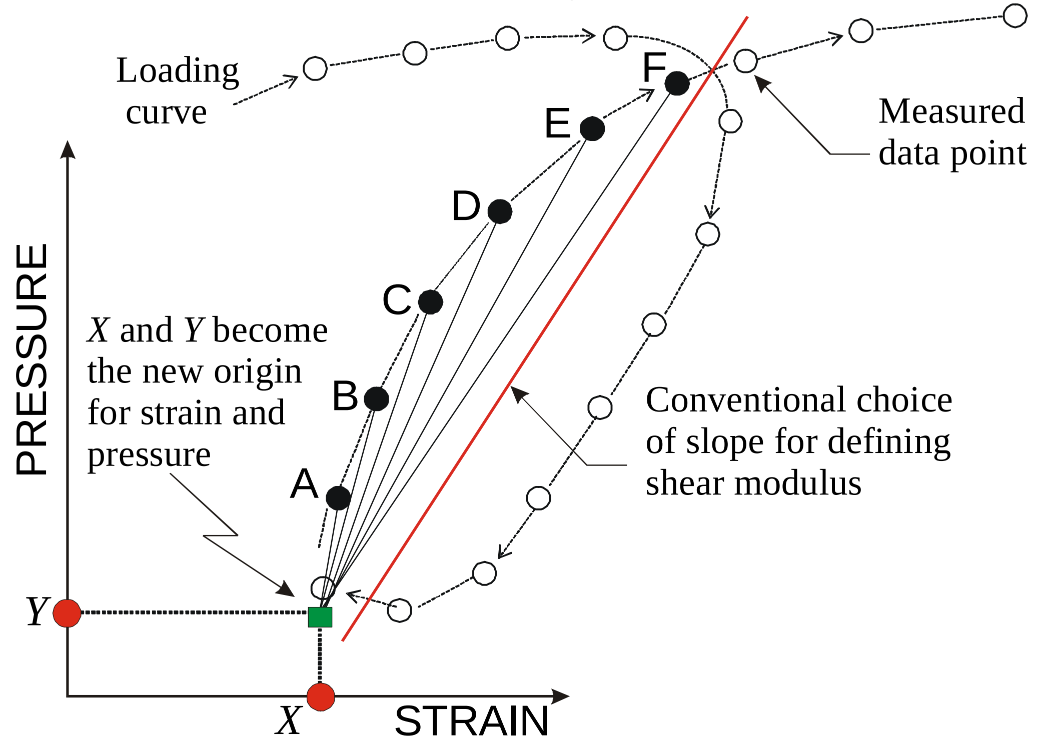
4.2 Non-linear stiffness/strain response

In recent times it has become widely acknowledged that the stiffness/strain relationship is not linear. The unload/reload cycle can be made to give a comprehensive description of this non-linear relationship by looking at smaller steps of pressure/strain other than the points at the extreme ends of the cycle.

For reasons explained in Whittle et al (1992) it is preferable to examine one half of the rebound cycle only, that which follows the reversal of stress in a loop. The lowest recorded value of stress and strain then becomes the origin for subsequent data points until the original loading path is rejoined.

In Fig 4.2, once a new origin is defined then every data point on the reloading part of the loop (A, B, C etc.) can be used to give a value for shear modulus. This value can then be plotted against the associated strain increment as measured from the new strain origin.

FIG 4.2 Annotated unload/reload cycle



The procedure for deciding the origin is not ideal - even better results for very small strains could be obtained if the origin were decided by inspection. The procedure suggested here is readily implemented on a spreadsheet, however, and means that any person handling the data will obtain identical results.

It follows that it is not necessary to take loops of small strain amplitude in order to obtain small strain stiffness parameters. Indeed it is better to make the cycles as large as possible in order to obtain parameters for as wide a strain range as possible.

It is often stated as a caution that unload/reload loops should have a pressure amplitude no greater than twice the mobilised shear stress (fig 1.1 shows why). Strictly speaking this is true, if one wants to use the whole loop to derive a single modulus parameter as in Fig 4.1.

However the response is still elastic immediately following the turnover point in the loop, so the data is by no means useless if an incremental approach is used. The real penalty for a loop that exceeds the elastic range of the material is a permanent and irrecoverable shift in the original strain origin; the loading curve following such a loop is *not* a continuation of the loading path prior to the loop.

Provided the loops were taken at the same effective stress then the data from all will plot the same trend. Conversely, if the loops plot one above the other then this indicates different effective stress conditions which in a clay test would prove that the expansion was not undrained.

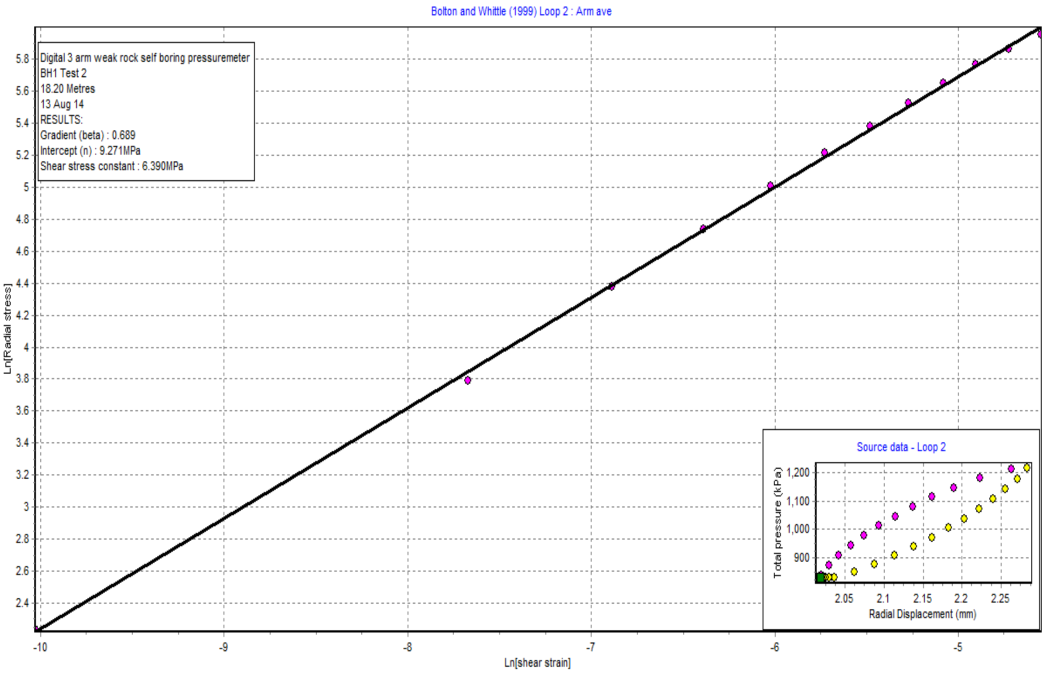


Fig 4.3 The non linear elastic response

Using the local origin for each cycle the reloading data can also be plotted on log axes of Δp_c versus $\Delta\gamma_c$. Figure 4.3 is an example. The gradient of the best-fit straight line to the data points is used within the Bolton & Whittle analysis as the non-linear elastic exponent β. The correspondence to a straight line is excellent.

The linear relationship between pressure and shear strain on log scales expands to a power law with the general form $p_c = \eta\gamma^\beta$ where p is the change in pressure measured at the borehole wall, γ is the corresponding shear strain and η and β are the intercept and gradient of the log log relationship.

4.3 From pressuremeter modulus to secant and tangential modulus

As shown in fig 4.3, the variation of stiffness with strain seen in a pressuremeter rebound cycle and in other soil tests can be expressed as a power law (Bolton & Whittle, 1996). Specifically, while the soil is responding elastically, pressure measured at the borehole wall is given by $p_c = \eta\gamma^\beta$ ... [Equ.4.2]

At first sight it would seem that the power law expression for secant shear modulus will be $G_p = \eta\gamma^{\beta-1}$ but this is not so. The Palmer result given by equation [3.21] still applies, therefore substituting for p_c using the right hand side of equation [4.2] allows the differential equation to be solved giving

$$\tau_c = \eta\beta\gamma^\beta \quad \text{... [Equ.4.3]}$$

$\eta\beta$ is equivalent to α, giving the modulus part of equation [3.1], the initial assumption of the Bolton & Whittle analysis.

Shear modulus G_s is given by τ_c/γ_c ... [Equ.4.4]
so the expression for secant shear modulus is given by $G_s = \alpha\gamma_c^{\beta-1}$ ... [Equ.4.5]

This gives a means of determining the secant shear modulus at any elastic shear strain, although an arbitrary cut-off strain must be assumed below which the modulus will be constant and a maximum – this strain is below the resolution of the SBPM.

Note:
When comparing triaxial results with pressuremeter results, invariant shear strain γ_T *is given by:* $\gamma_T = \gamma_c / \sqrt{3}$ ... [Equ.4.6]

Tangential shear modulus G_t is given by $G_t = G_s + \varepsilon_c[dG_s/d\varepsilon_c]$ ... [Equ.4.7]
Hence from the power law $G_t = \alpha\beta\gamma_c^{\beta-1}$ ... [Equ.4.8]

For the purpose of finding the single value of secant shear stiffness governing the pressuremeter response seen in the measured loading curve, G_{100} is required. This is the secant modulus at the maximum elastic shear strain, sometimes termed G_{min} or G_{yield}. It is probably too conservative a value for design purposes.

There is an alternative way of deriving G_s and G_t from pressuremeter unload/reload cycles, what might be described as the transformed strain approach. If the data points of an unload/reload cycle are used to derive a *pressuremeter* modulus G_P (in effect $\Delta p_c/\Delta\gamma_c$) curve then Jardine (1991) gives two empirically derived expressions for G_s and G_t.

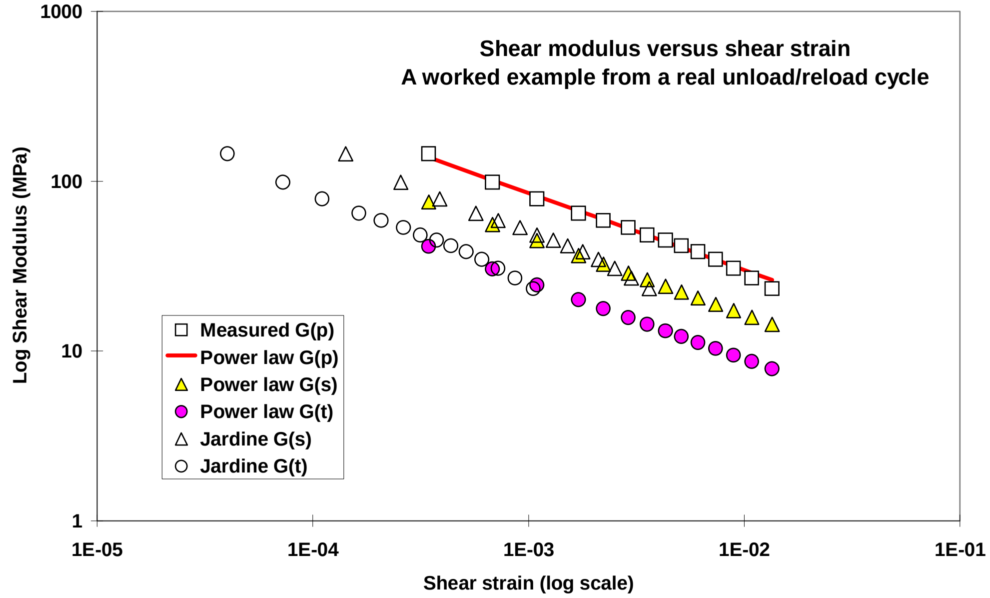


Fig 4.4 **Alternative ways of plotting stiffness strain curves**

The expressions are:-

$\gamma_c/\gamma_s = 1.2 + 0.8 \log_{10}(\gamma_c/10^{-5})$ for converting G_P to G_s ... [Equ.4.9]

and

$\gamma_c/\gamma_s = 4.5 + 2.65 \log_{10}(\gamma_c/10^{-5})$ for converting G_P to G_t [Equ.4.10]

The effect of applying equations [4.9] and [4.10] is to re-calculate the strain at which a given value of pressuremeter modulus applies.

Figure 4.4 shows all these possible ways of quoting modulus applied to a single unload/reload cycle from a pressuremeter test in clay. There is good agreement between the empirically derived Jardine transformations and the rigorous derivatives from the power law expression.

4.4 Stress level

For modulus parameters derived from undrained expansion tests the mean effective stress remains unchanged throughout the expansion and all stiffness:strain data will plot the same trend. Conversely, failure to plot the same trend implies changes in the mean effective stress. This is true of tests affected by consolidation, but is also true of a heavily disturbed loading where the effects of the pressuremeter installation method have yet to be overcome. For such data it is reasonable to take modulus parameters from as late in the loading as possible. Division of the modulus values by a normalising stress such as the effective insitu lateral stress or yield stress gives a dimensionless parameter for modelling purposes.

Reducing the unload/reload cycles from drained tests is a more complex process and is not described here.

4.5 Cross hole anisotropy

The pressuremeter test gives values for G_{HH}, the shearing stiffness in the horizontal plane. This is directly applicable to the analysis of radial consolidation or cylindrical cavity expansion due to pile insertion. G_{VH} is applicable all shearing which has an element of deformation in the vertical plane, such as under a footing or round an axially loaded pile.

To convert from G_{HH} to G_{VH} some relationship between the two must be assumed. Wroth et al (1979) suggest that anisotropy arises from two causes:
Structural anisotropy due to the deposition of soil on well defined planes
Stress induced anisotropy, due to the differences in normal stress acting in different directions.

The second cause implies the stiffness in any direction will be a function of the effective insitu stress in that direction, ie a function of K_O.

It can be shown $G_{HH} = E_H/[2(1+\nu_{HH})]$ ... [Equ.4.11]
For undrained expansion $\nu_{HH} = 1-n/2$ ... [Equ.4.12]
and $n = E_H/E_V = K_O$ ... [Equ.4.13]
From this it follows $E_H = (4-n)G_{HH}$ ... [Equ.4.14]
and $E_V = (4-n)G_{HH}/n$ ... [Equ.4.15]

This is as far as argument from first principles can go, because of the additional contribution of the manner in which the material is deposited. K_O is likely to lie between 0.5 and 2, so from equation [4.13] E_H/G_{HH} lies between 2 and 3.5. From equation [4.15] E_V/G_{HH} lies between 1 and 1.75.

It is likely that G_{VH} will be linked to E_V by Poisson's ratio in a relationship of the form of equation [4.15]. Plausible values of E_V/G_{VH} would seem to be 2.4 to 3. Hence in a material with K_O of 2, G_{VH} could be as low as $G_{HH}/3$. Simpson et al (1996) come to the same conclusion, but find in practice heavily over-consolidated London clay gives relationships of the order of $G_{VH} \cong 0.65G_{HH}$. The influence of the strain range is not separately considered in these studies, and it is quite possible that the G_{100} values would be similar in all planes.

Lee & Rowe (1989) give details of the anisotropy characteristics of many clays varying from lightly overconsolidated to heavily overconsolidated. The general conclusion is E_V/G_{VH} lies between 4 and 5, rather more than the isotropic relationship of 3. However their paper was concerned with the impact of anisotropic stiffness properties on surface settlement. Deriving G_{VH} from E_V is therefore unsatisfactory, because although G_{VH} is insensitive to the direction of loading, E_V is not.

In material with a K_O of 1 it is likely that G_{VH} will be similar to G_{HH}. For values of K_O smaller than 1 then the vertical shear modulus G_{VH} may even be greater than the horizontal value.

4.6 Recommendations for manipulating pressuremeter unload/reload data

- Convert all the unload/reload cycle data to a power law expression.
- Derive the parameters for the secant and tangential modulus expressions.
- Decide the shear strain of interest, and derive the appropriate secant and tangential stiffness.
- Determine K_O .
- Given K_O, derive E_H, E_V and G_{VH}.

4.7 Shear modulus from other parts of the pressuremeter curve.

The initial part of the loading will give a value for secant shear modulus, usually referred to as G_i. Provided the insertion disturbance is low this will be a plausible value but affected by the same considerations of stress level and strain range as other parts of the curve.

The first part of the unloading can in principle give a similar parameter but by the time the pressuremeter unloads the creep strains due to consolidation and rate effects will be large, so there will be a tendency for the initial unloading to be too stiff. However provided some allowance is made for this then reasonable estimates of the shear modulus will be obtained.

Analyses such as Bolton & Whittle also imply a value for the secant shear modulus at yield – it will be c_u/γ_{ye}, called G_{ye} in Fig 3.1. Although this is not likely to be the best way of deriving shear modulus data it is important justification for using the analysis that it can predict this independently measurable stiffness.

5. Deriving values for over consolidation ratio from pressuremeter data

5.1 Overview

Soil is overconsolidated when its current state of stress is less than the maximum stress it experienced in the past. There are a number of ratios that could be called the over consolidation ratio (OCR) but the particular one under discussion here is R_P where $R_P = p'_Y / p'_A$ and is the ratio of maximum past effective stress to the current effective stress. For our purposes p'_A is the effective overburden stress and is usually easy to estimate to a suitable accuracy.

5.2 Wroth 1984

Wroth (1984) gives a correlation, using critical state soil mechanics nomenclature, between the undrained shear strength ratio and OCR:

$$\frac{c_u}{\sigma'_{vo}} = \frac{M}{2}\left(\frac{R_p}{r}\right)^{\Lambda} \qquad \text{..... Equ [5.1]}$$

where C_U is undrained shear strength

σ'_{vo} is the effective overburden stress

M is the frictional coefficient = $= 6\sin\phi / (3 - \sin\phi)$ and is ≈ 1 for typical values of Φ.

r is the spacing ratio between equivalent points on the isotropic consolidation line and critical state line and is ≈ 2

Λ is the plastic volumetric strain ratio and for most clays is ≈ 0.8

The labelling here is slightly different from the published form, and in particular Wroth takes care to specify that the undrained shear strength and friction angle are triaxial test parameters, not those from plane strain shearing. Nevertheless in view of the other uncertainties these are minor objections and combining these assumptions leads to the following:

$$R_p = 2\left[\frac{2c_u}{\sigma'_{vo}}\right]^{\frac{1}{\Lambda}} \qquad \text{..... Equ [5.2]}$$

Ladd et al (1977) quote a similar expression using classical soil mechanics terminology, and this can be re-arranged to give the following:

$$R_p = \left[\frac{c_u}{\sigma'_{vo}\left(0.11 + 0.0037\, I_p\right)}\right]^{\frac{1}{m}} \qquad \text{..... Equ [5.3]}$$

where I_P is plasticity index. Ladd et al (1977) note that the exponent *m* reduces slightly with increasing OCR and has the range 0.85 to 0.75. Wroth ('84) states that m ≡ Λ.

Equation 5.3 is related to an earlier empirical formulation offered by Skempton (1957) for natural deposits of clay normally consolidated:

$$\frac{c_u}{\sigma'_{vo}} = 0.11 + 0.0037\, I_p$$ ..... Equ [5.4]

Note that the values of shear strength used to develop the Skempton correlation were obtained from vane tests. This suggests that there is rather better agreement between values of shear strength obtained from different modes of testing than is generally supposed.

Wroth ('84) also offers the following:

$$\hat{R}_p = \frac{\left(c_u / \sigma'_{vo}\right)}{\left(c_u / \sigma'_{vo}\right)_{nc}}$$ ..... Equ [5.5]

which normalises the undrained strength ratio and is independent of the frictional coefficient *M* and the spacing ratio *r*.

Based on equ [5.2], when values for OCR are given in our data, we use the following:

$$R_p = 2\left(2C_u / \sigma'_{vo}\right)^{5/4}$$ ..... Equ [5.6]

6. Inferring values for the angle of friction from undrained tests

In principle the drained angle of internal friction ϕ can be derived from undrained results via the following, being the slope of the Mohr's circle relating normal stress to shear stress:

Let the mean effective normal stress be S':

$$S' = (\sigma'_{vo} + \sigma'_{ho}) / 2 \qquad [6.1]$$

Then

$$\sin \phi = c_u / S' \qquad [6.2]$$

where c_u is undrained shear strength. This seldom gives credible values for ϕ using pressuremeter derived results, especially in over-consolidated clays.

When examining vane results, Wroth ('84) gives the following relationship between undrained *maximum* shear stress and friction angle:

$$\tau_{max} = \sigma'_{ho} \sin \phi_{ps} \qquad [6.3]$$

The right hand side represents the shear stress to failure in the classic Mohr – Coulomb definition of yield stress. By itself this expression also seems to give unlikely values for friction angle, but when modified to take account of non-linearity (Bolton & Whittle, 1999) can be re-arranged and written in terms of undrained shear strength:

$$\sin \phi_{ps} = \left[\left(\frac{\sigma'_{ho}}{c_u} \right) - \left(\frac{1-\beta}{\beta} \right) \right]^{-1} \qquad [6.4]$$

where β is the exponent of non-linearity, lies between 0.5 and 1, and 1 is linear-elastic. The non-linear argument is that the failure stress τ_{max} is c_u / β. If β is 1 then [6.3] and [6.4] are identical.

This expression seems to give sensible values for ϕ_{ps} but the results are speculative. Note that triaxial test determined values for friction angle, ϕ_{tx}, are not the same as ϕ_{ps}. Wroth ('84) gives $8\phi_{ps}. \approx 9\phi_{tx}$.

APPENDIX E Sample calculation of a line of data

What are described in some detail in this appendix are the steps necessary to convert the raw data output from the pressuremeter into engineering units. The data line used is from an imaginary test S01T4 and is line no. 332.

In order to convert self boring pressuremeter signals into calibrated data the following steps are taken:

A. The raw data is in units of volts, and needs to be corrected for zero offsets and scaled using the sensitivities quoted in the calibration data.

The calibrations for this particular test are presented as follows:-

INSTRUMENT CALIBRATIONS: S01T4 DEPTH: 8.50m DATE: 21 AUG 13

	ZERO		SLOPE		STIFFNESS & COMPLIANCE						
ARM 1	-344.9	&	302.7	mV/mm	38.2	kPa	&	9.1	kPa/mm	3.8	mm/GPa
ARM 2	145.0	&	288.8	mV/mm	38.2	kPa	&	9.1	kPa/mm	3.8	mm/GPa
ARM 3	-277.1	&	291.2	mV/mm	38.2	kPa	&	9.1	kPa/mm	3.8	mm/GPa
TPC	-1401.6	&	402.7	mV/mm							
PPC A	-14.8	&	234.6	mV/mm							
PPC B	-1877.8	&	244.5	mV/mm							

The line of raw data reads from left to right as follows. Note that the units are volts:-

LINE	ARM 1	ARM 2	ARM 3	TPC	PPC A	PPC B
332	0.9758	1.5227	1.0256	-1.2234	0.0036	-1.8586

The first operation is to deduct the zero offsets. These are the figures found in the first column of the calibration information. They are quoted here in volts:-

	ARM 1	ARM 2	ARM 3	TPC	PPC A	PPC B	
Outputs	0.9758	1.5227	1.0256	-1.2234	0.0036	-1.8586	
Zero	-0.3449	0.1450	-0.2771	-1.4016	-0.0148	-1.8778	
Result	1.3207	1.3777	1.3027	0.1782	0.0184	0.0192	[1]

This result can now be scaled. The information for this is found in the second column of calibration data, and is expressed as millivolts per millimetre to calculate displacement, and as millivolts per megaPascal to calculate pressure. They are written below as volts:-

	ARM 1	ARM 2	ARM 3	TPC	PPC A	PPC B	
From [1]	1.3207	1.3777	1.3027	0.1782	0.0184	0.0192	
Slope	0.3027	0.2888	0.2912	0.4027	0.2346	0.2445	
Result	4.3631	4.7704	4.4736	0.4425	0.0784	0.0785	[2]
	(mm)	(mm)	(mm)	(MPa)	(MPa)	(MPa)	

B. The data is now in engineering units which reflect what is taking place inside the membrane. The remaining corrections are introduced to give a better representation of what is taking place at the point where the membrane bears on the borehole wall.

The pressure information is in units of MPa and must be adjusted for membrane stiffness. This is calculated separately for each strain arm, but note that the average strain is used to apply the slope correction:-

The displacement data is adjusted for the instrument displacements due to the pressure being applied to it. This is expressed as a linear movement in millimetres per gigaPascal of pressure being applied, and is found in the 5th column of the calibration details:

	ARM 1	ARM 2	ARM 3	
Correction Factor (mm/GPa)	3.8	3.8	3.8	[3]
Internal Pressure (MPa)	0.4425	0.4425	0.4425	from result [2]
Adjustment ([3]*[2])/1000	0.0017	0.0017	0.0017	[4]
Internal Displacement (mm)	4.3631	4.7704	4.4736	from result [2]
Corrected Displacement (mm)	4.3614	4.7687	4.4719	[5]

C. The strain data calculated so far is the movement measured by the strain arms to the inside of the membrane. The figures quoted in the calibrated data listings are the movement of the outside of the protective sheath. This is derived from the internal strain movement by assuming that the cross-section area of the memebrane is a constant. A full explanation of this and the derivation of the equation used is discussed in the appendix on calibration technique.

The equation is $E = \sqrt{[(R-t)^2 + D(2r+D)}] - (R-t)$ [6]

where E is the actual expansion of the pressuremeter
2R is the O.D of the pressuremeter at rest
2r is the I.D of the membrane at rest
D is the movement measured by the strain arm
t is the thickness of the chinese lantern steel

For the pressuremeter used to produce this example:-

2R = 89.00 mm
2r = 79.15 mm
t = 0.5334 mm

Because the membrane can be assumed to have the same thickness at all points on the cross-section the technique employed is to calculate a scale factor from the average strain.

	ARM 1	ARM 2	ARM 3	
Corrected Displacements	4.3614	4.7687	4.4719	(from result [5]
Average Displacement	4.5340			[6]
Res. of equ [6] using D = [6]	4.1217			[7]
Scale Factor [7]/[6]	0.9091			[8]
Apply [8] to [5]	3.9648	4.3351	4.0652	[9]

D. The next step is to calculate the total membrane correction that needs to be made for each arm position. This is the sum of the zero figure plus the increased stiffness with strain. This second component uses the fourth column of calibration data and is quoted as kPa per millimetre movement:-

	ARM 1	ARM 2	ARM 3	
Ave. Displacement	4.1217			
Slope per mm (kPa)	9.1	9.1	9.1	[10]
Result [10]*[7] (kPa)	37.5	37.5	37.5	[11]
Correction zero (kPa)	38.2	38.2	38.2	[12]
Add zeroes to result [8]	75.7	75.7	75.7	[13]

This is the total membrane correction at each arm position and is now deducted from the total pressure cell readings to give three files of corrected pressure. Because [13] above is the same for all arms (not always the case) the result is three columns of identical total pressure:

	TPC 1	TPC 2	TPC 3	
Uncorrected pressure in kPa	442.5	442.5	442.5	(from result [2])
Membrane correction in kPa	75.7	75.7	75.7	(from result [13])
RESULT	366.8	366.8	366.8	[10]

The pressure data is now in its final form. The data from the two pore pressure cells need only to be quoted in kPa rather than MPa to be complete.

The result, as output by the logging software, using displacements from [9], uncorrected Total Pressure from [2] and Pore Pressures from [2].

NO	ARM 1	ARM 2	ARM 3	TPC 1	TPC 2	TPC 3	PPC A	PPC B
332	3.9648	4.3351	4.0652	366.8	366.8	366.8	78.4	78.5

In practice the errors introduced by rounding-off calculations may result in small differences in the final figure.

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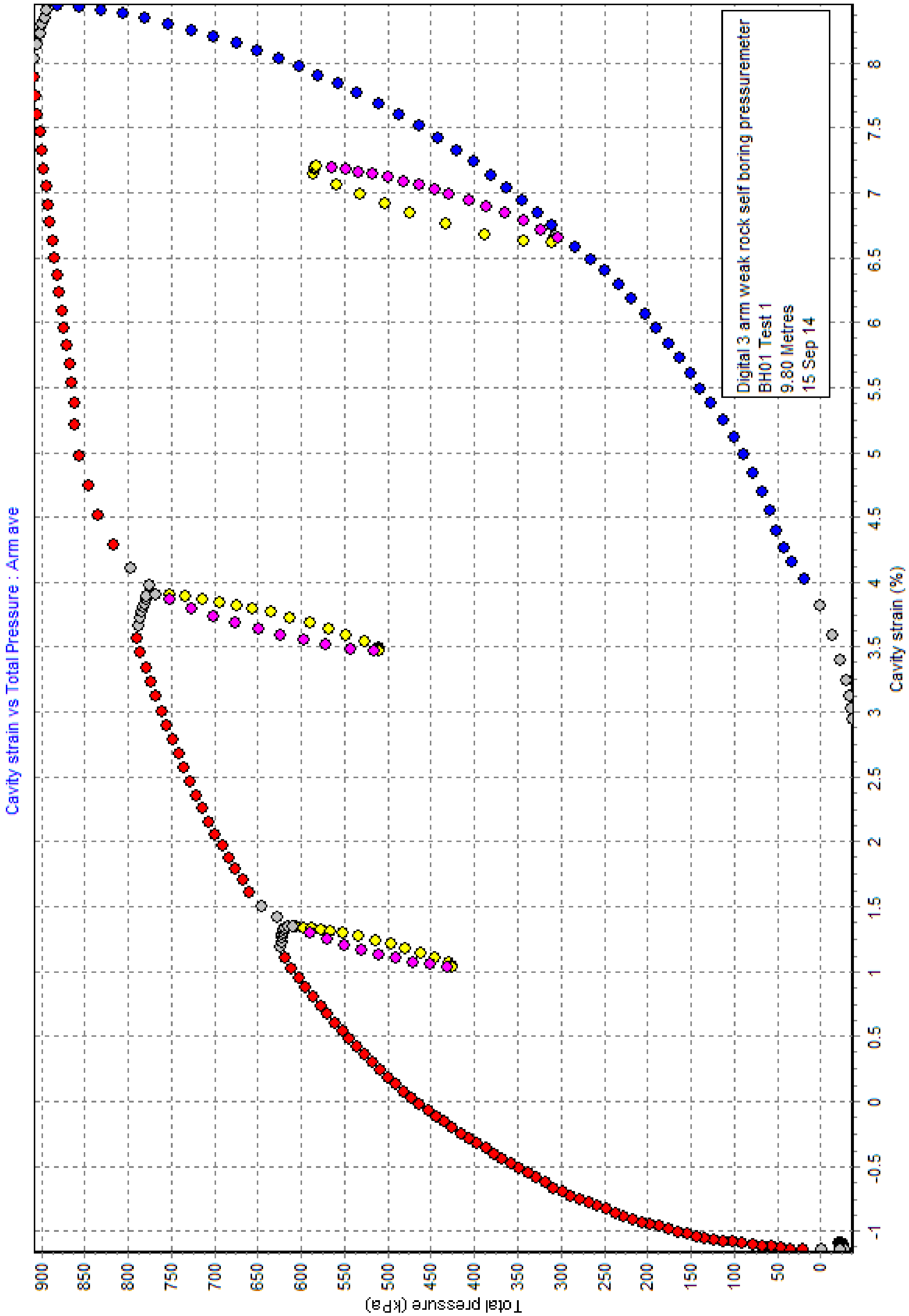
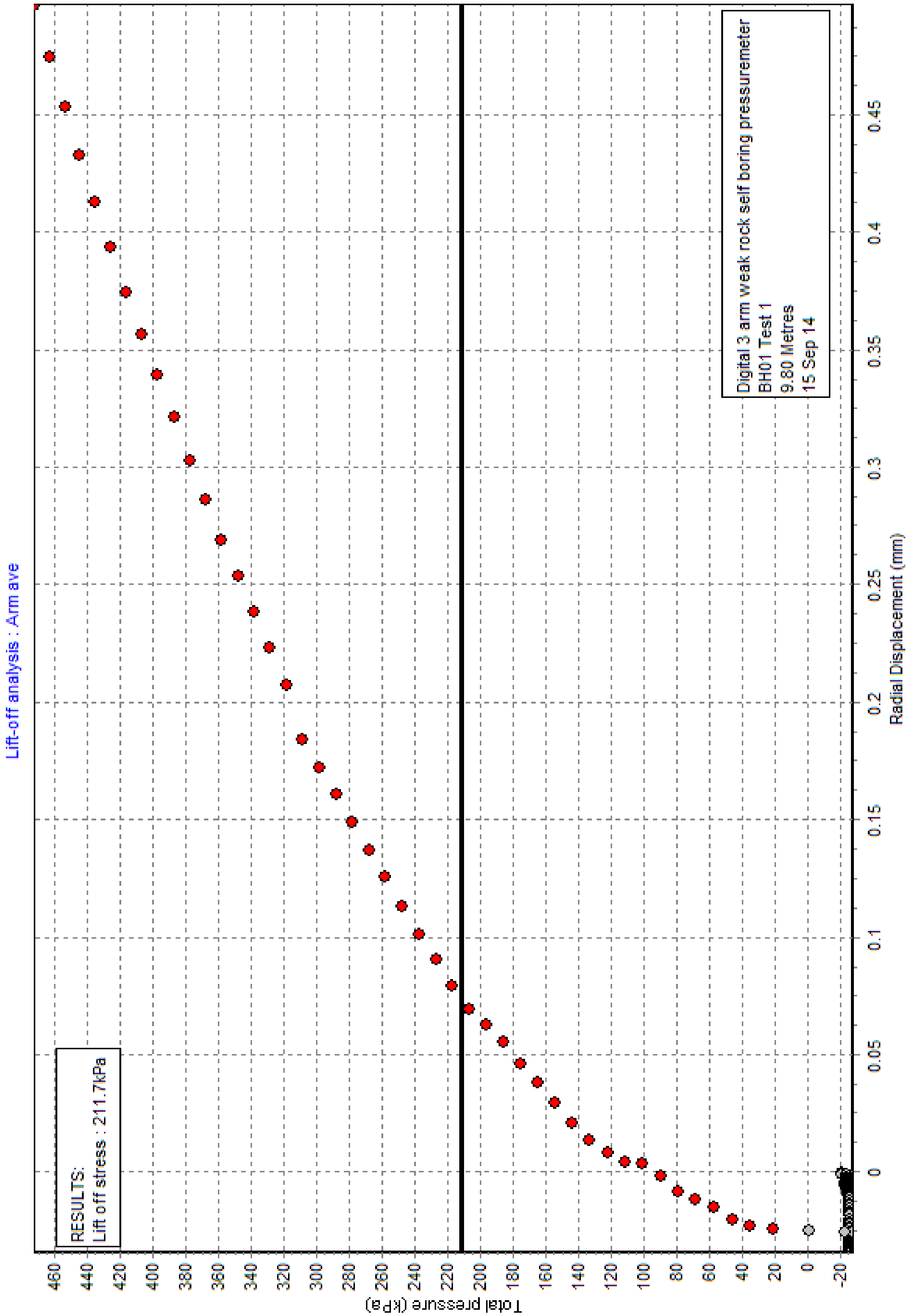
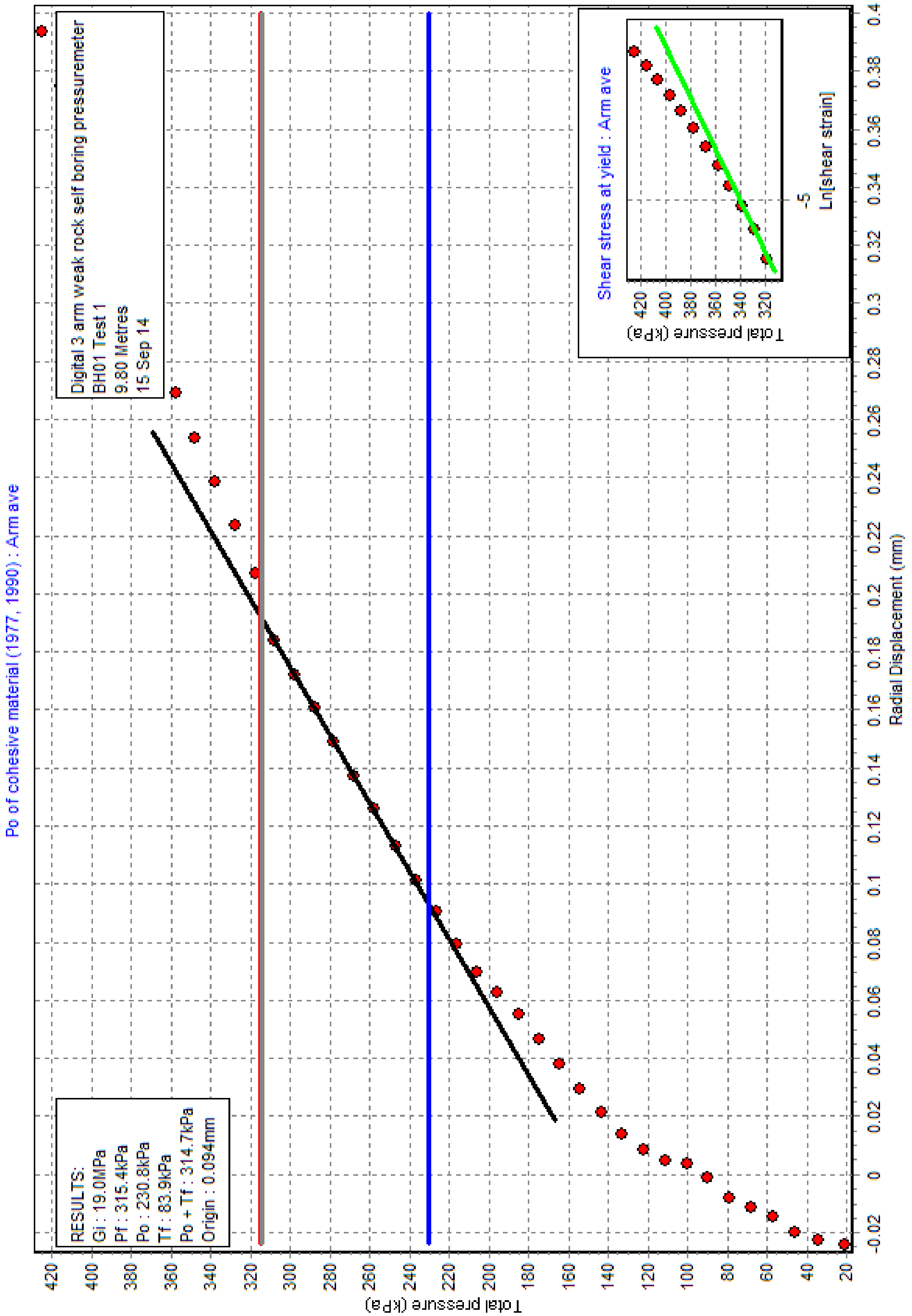
APPENDIX G TEST DATA

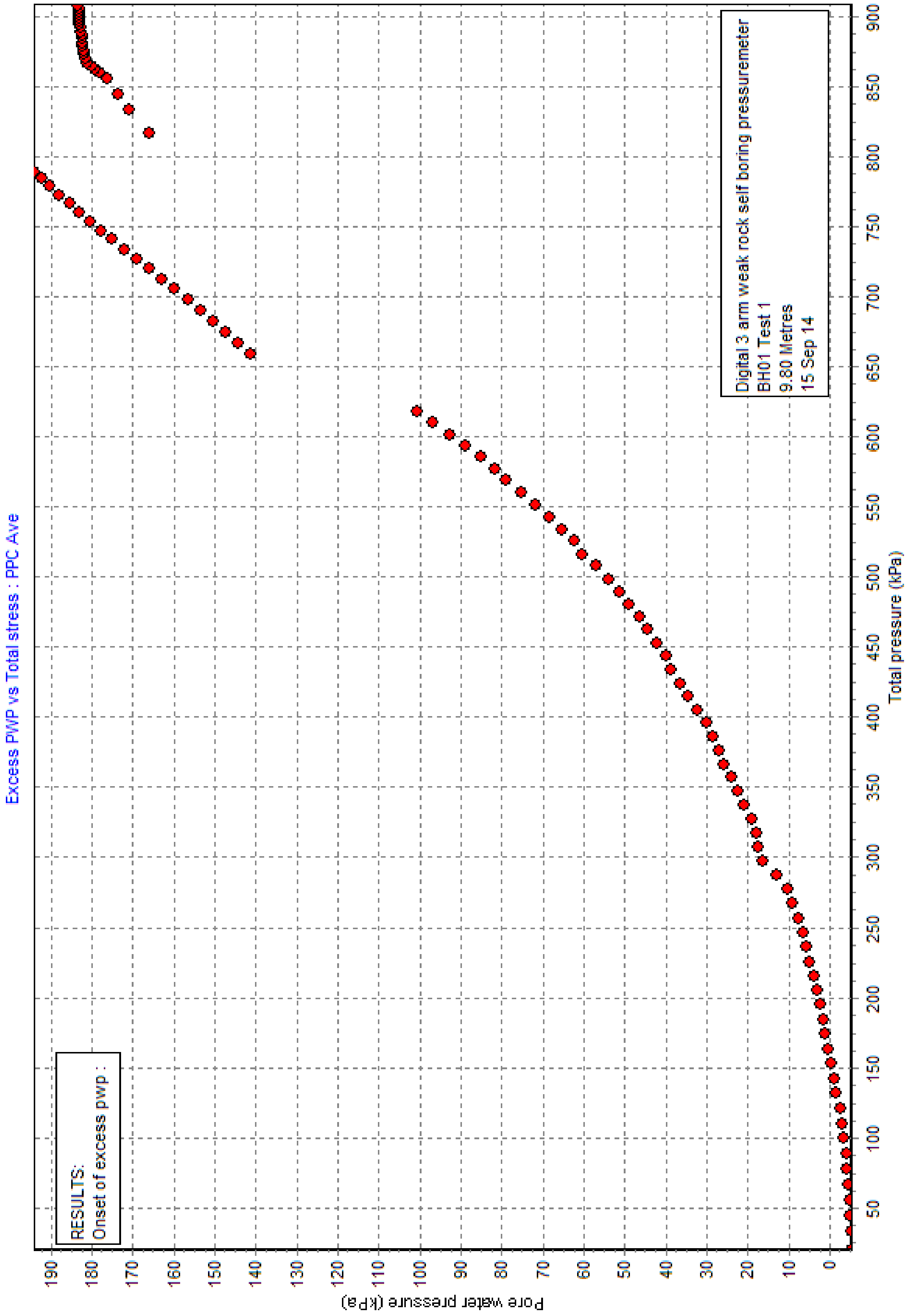
BH1 Test 1	9.8 mBGL
BH1 Test 2	15.3 mBGL
BH1 Test 3	20.0 mBGL
BH1 Test 4	25.0 mBGL

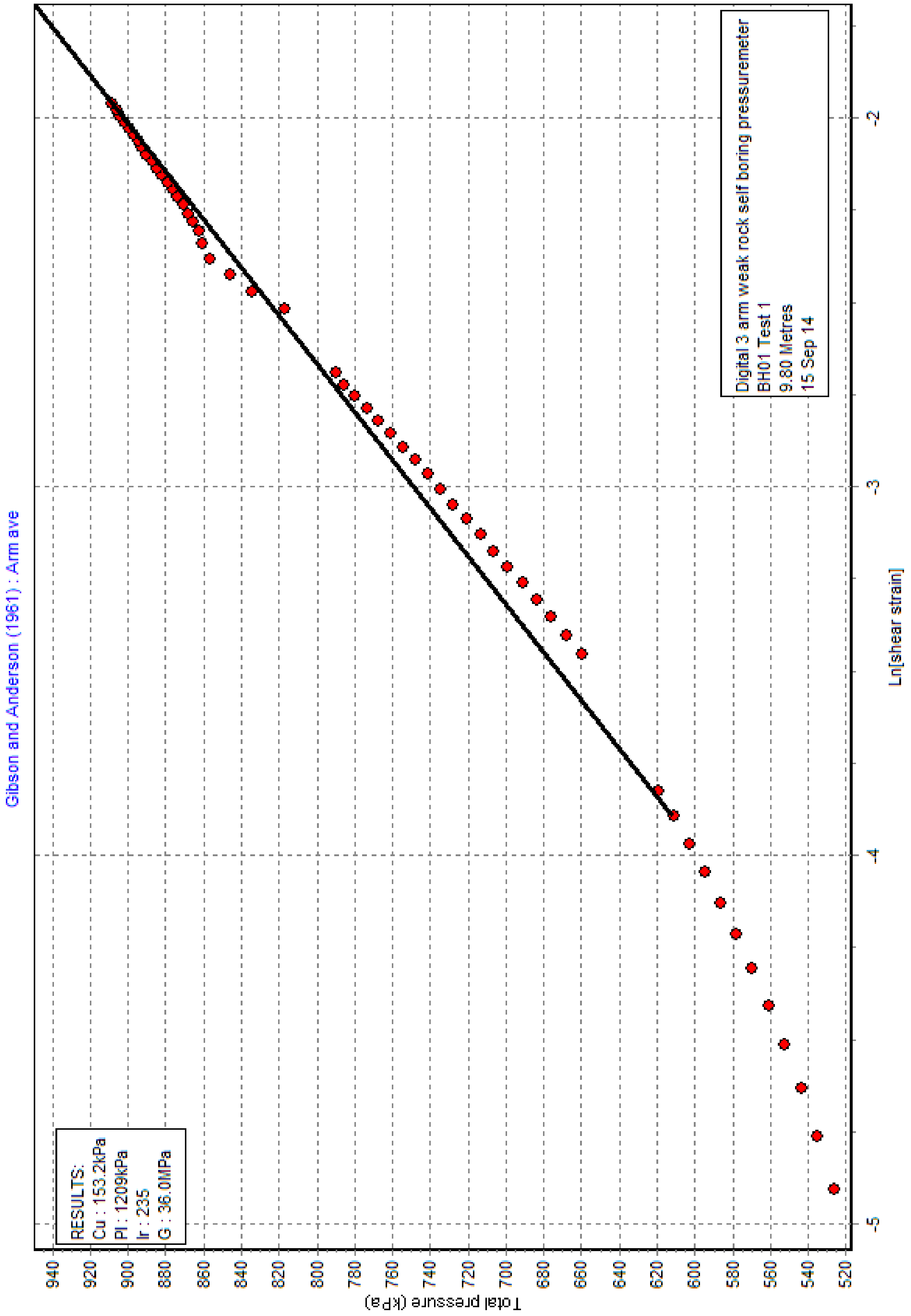
```
BH01 Test 1 - SUMMARY OF RESULTS
[File made with WinSitu  Version 3.6.1.1]

[DETAILS OF TEST]
Project        :
Site           :   1 Bedford Avenue
Borehole       :   BH01
Test name      :   BH01 Test 1
Test date      :   15 Sep 14
Test depth     :   9.80 Metres
Water table    :   Nothing entered
Ambient PWP    :   0.0 kPa
Material       :   London Clay
Probe          :   Digital 3 arm weak rock self boring pressuremeter
Diameter       :   88.1 mm
Data analysed using average arm displacement curve
A non-linear analysis of the rebound cycles has been carried out
The file includes results from a curve fitting analysis

Analysed by SDB on 14 Oct 14

Remarks:

[RESULTS FOR CAVITY REFERENCE PRESSURE]
Strain Origin (mm)                  :   "Arm ave=0.480"
Po from Marsland & Randolph (kPa)   :   "Arm ave=230.8"
Po from Lift off (kPa)              :   "Arm ave=211.7"
Best estimate of Po (kPa)           :   "Arm ave=219.0"

[UNDRAINED STRENGTH PARAMETERS]
Gibson & Anderson 1961 - Cu (kPa)   :   "Arm ave=153.2"
Limit pressure (kPa)                :   "Arm ave=1209"
Jefferies 1988 - Cu (kPa)           :   "Arm ave=150.9"
Undrained yield stress (kPa)        :   "Arm ave=315.4"

[LINEAR INTERPRETATION OF SHEAR MODULUS G]
Initial slope shear modulus (MPa) :"Arm ave=19.0"
Axis       Loop   Value    Mean Strain  Mean Pc  dE      dPc
           No     (MPa)    (%)          (kPa)    (%)     (kPa)
Arm ave    1      30.1     1.200        515      0.594   179
Arm ave    2      30.1     3.694        633      0.818   247
Arm ave    3      26.1     6.908        447      1.049   275

[UNDRAINED NON LINEAR INTERPRETATION OF SECANT SHEAR MODULUS]
Axis       Loop   Intercept  Alpha      Gradient
           No     (MPa)      (MPa)
Arm ave    1      6.933      4.897      0.706
Arm ave    2      6.841      4.660      0.681
Arm ave    3      5.848      3.840      0.657


[PARAMETERS USED FOR UNDRAINED CURVE MODELLING]
{Axis is  Arm ave}
Strain Origin (mm)                  :   0.48
Po (kPa)                            :   219
Cu (kPa)                            :   153.2
Limit pressure (kPa)                :   1209
Non-linear exponent                 :   0.657
Calculated alpha (MPa)              :   3.929
G at yield (MPa)                    :   21.4
```

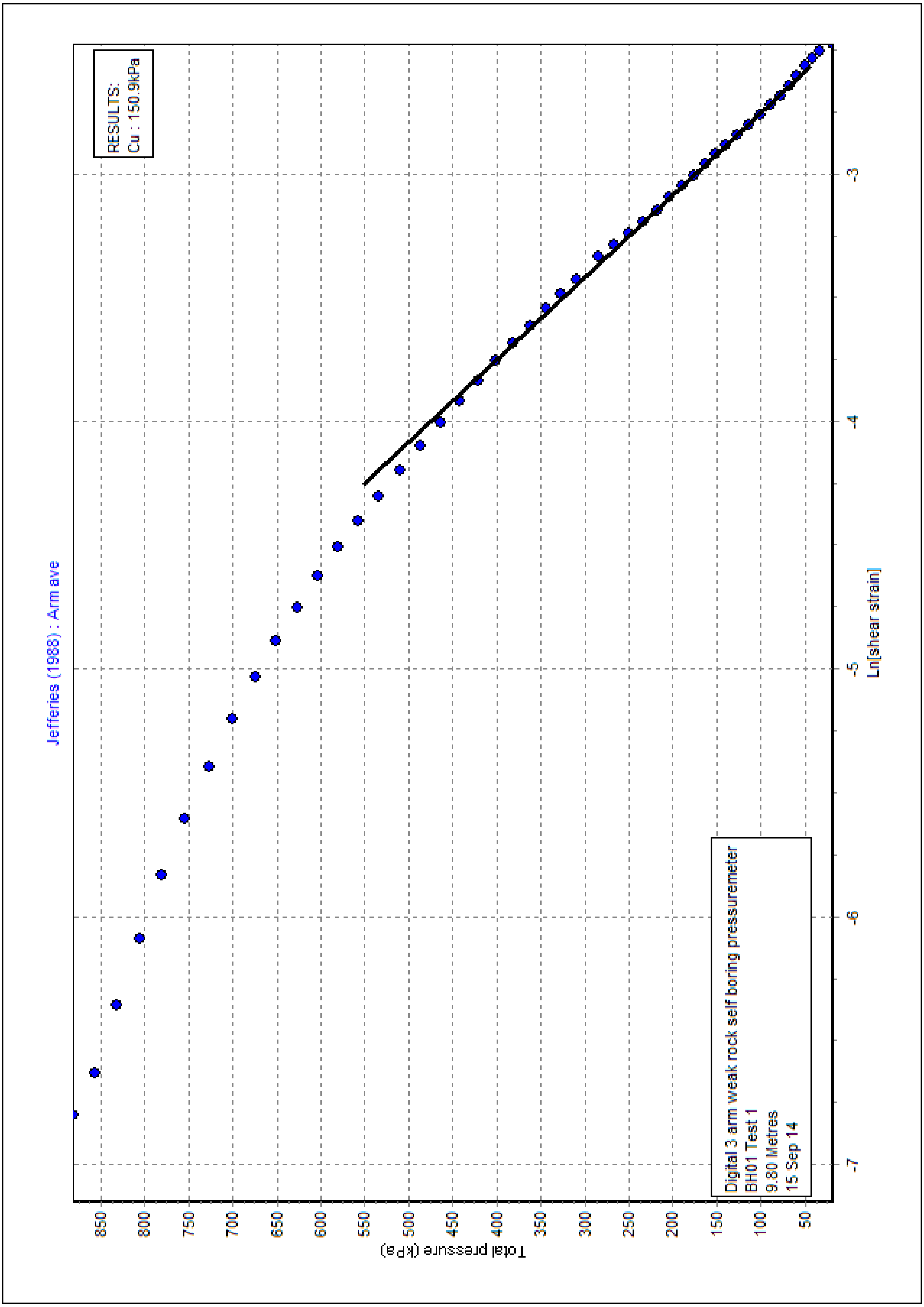

Cavity strain vs Total Pressure : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 1
9.80 Metres
15 Sep 14
Total pressure (kPa)
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Cavity strain (%)
-1
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8

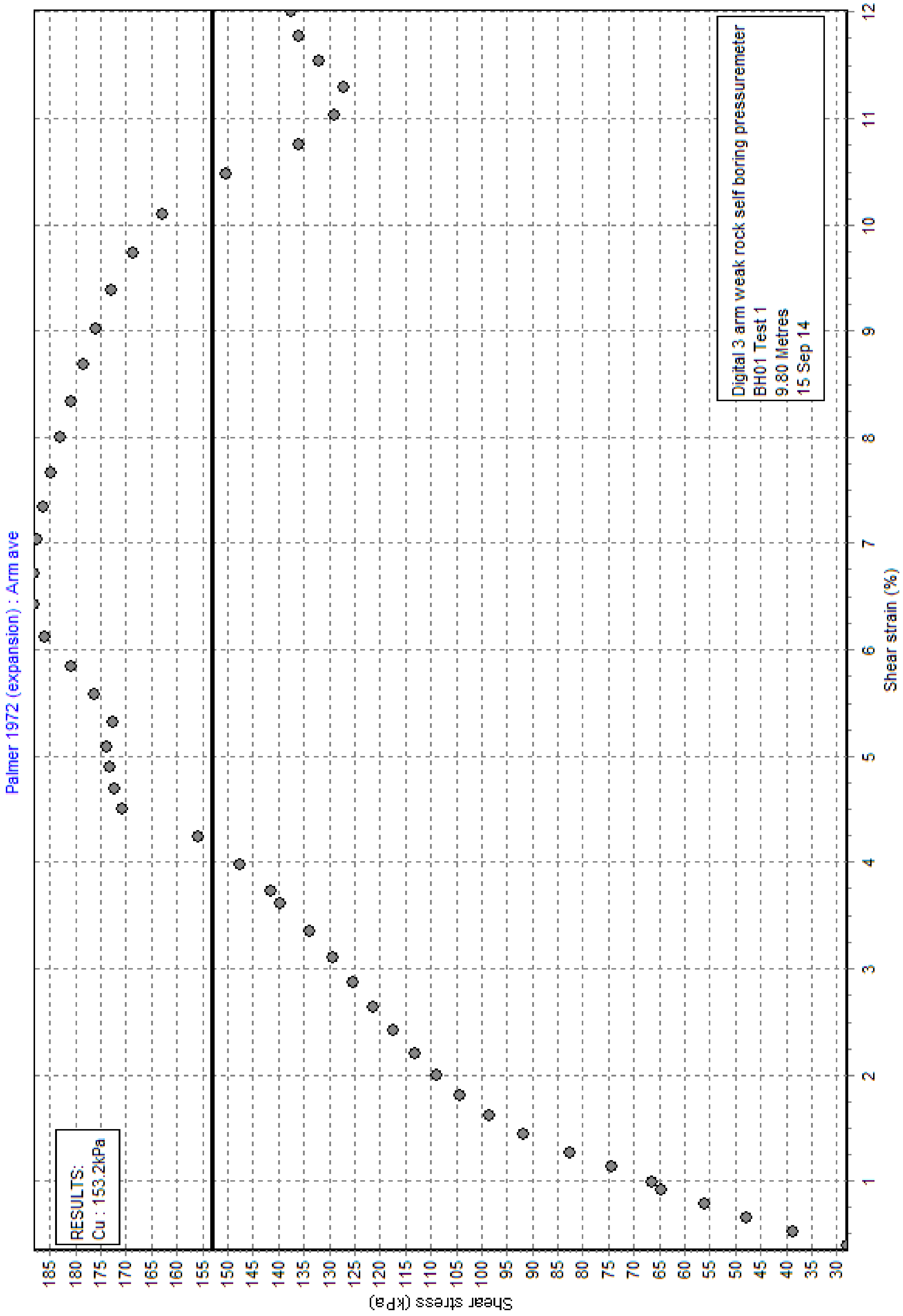

Lift-off analysis : Arm ave
RESULTS:
Lift off stress : 211.7kPa
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 1
9.80 Metres
15 Sep 14
Total pressure (kPa)
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
Radial Displacement (mm)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45

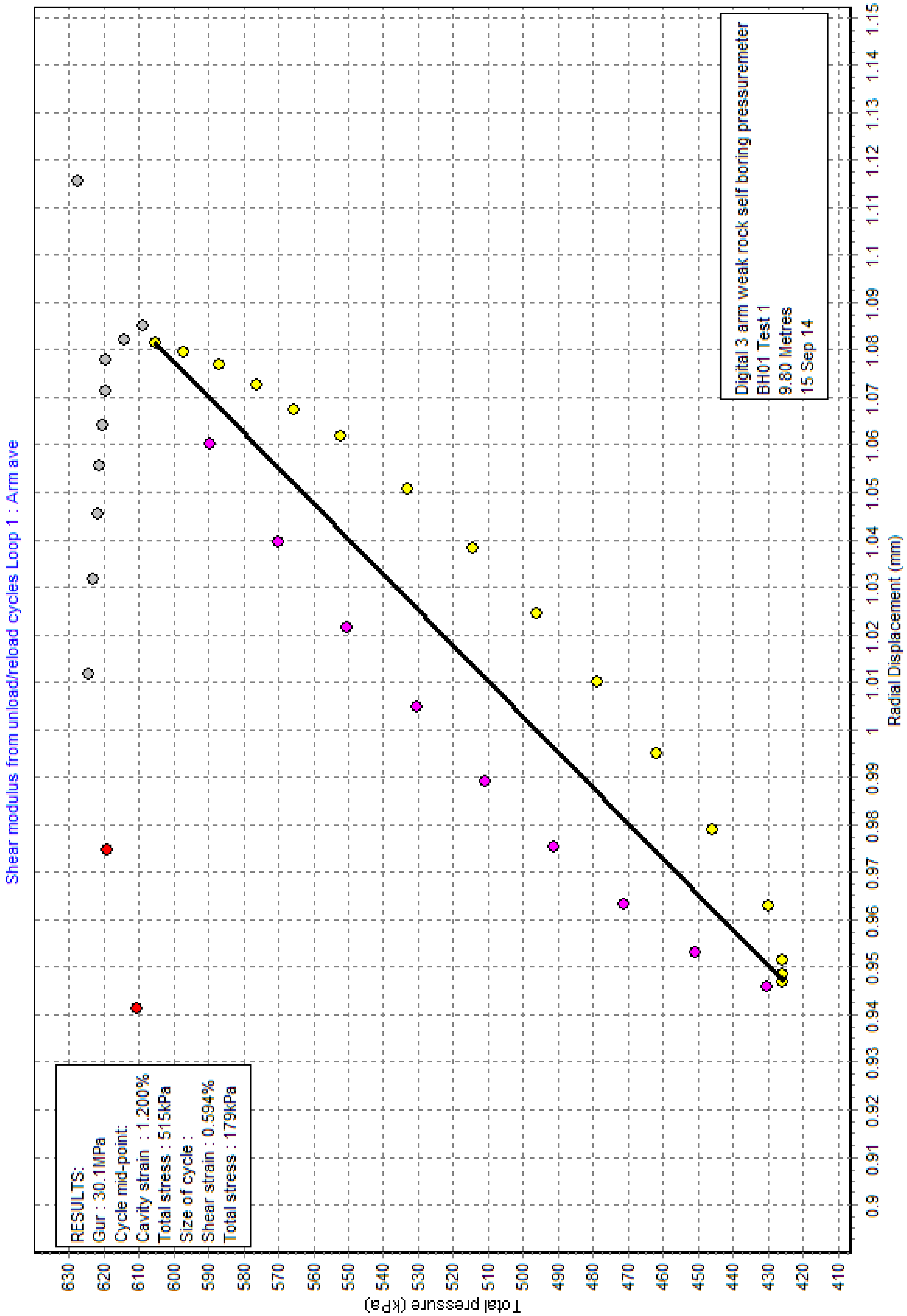

Po of cohesive material (1977, 1990) : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 1
9.80 Metres
15 Sep 14
RESULTS:
Gi : 19.0MPa
Pf : 315.4kPa
Po : 230.8kPa
Tf : 83.9kPa
Po + Tf : 314.7kPa
Origin : 0.094mm
Total pressure (kPa)
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
Radial Displacement (mm)
-0.02
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
0.28
0.3
0.32
0.34
0.36
0.38
0.4
Shear stress at yield : Arm ave
Total pressure (kPa)
420
400
380
360
340
320
-5
Ln[shear strain]

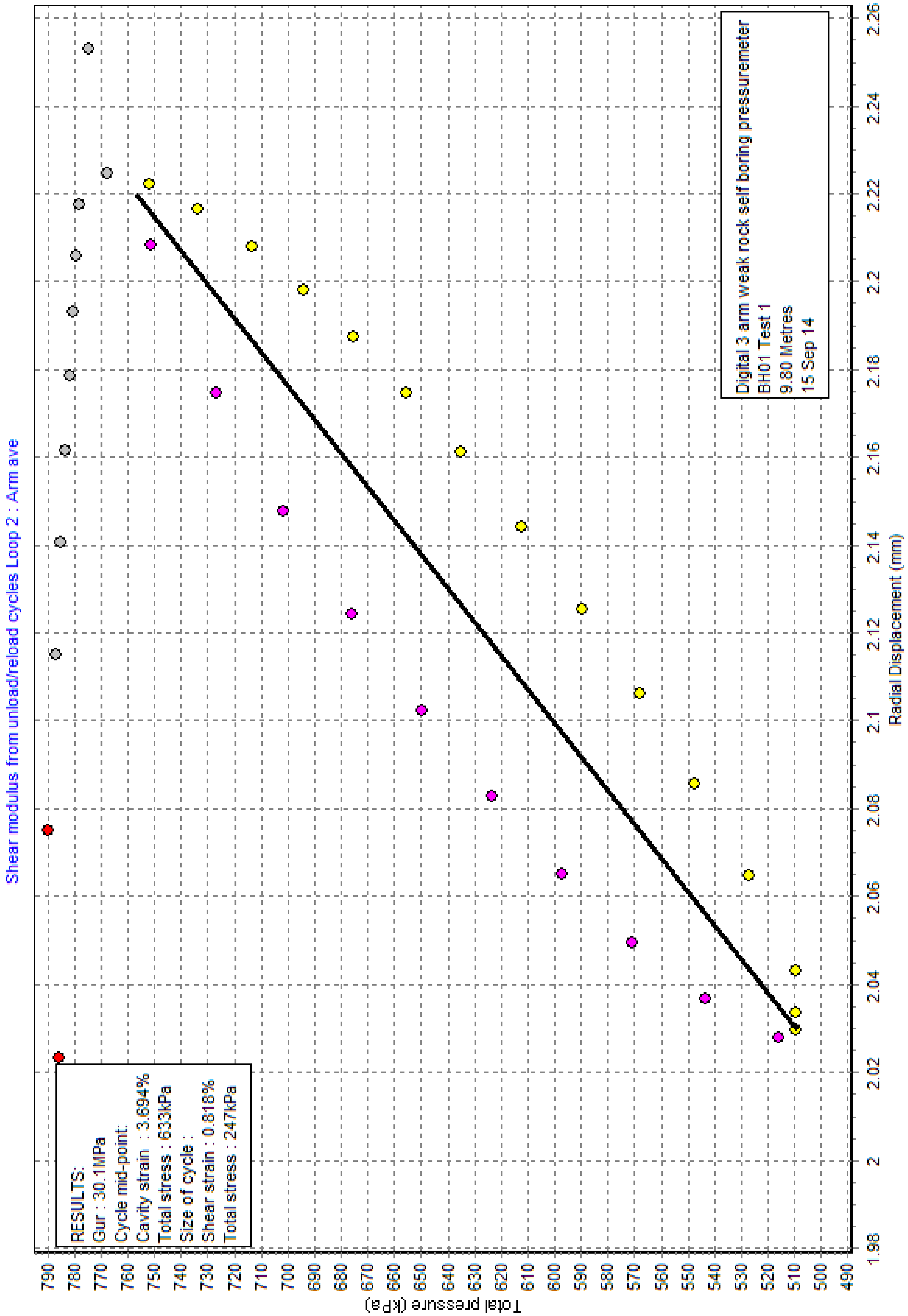

Excess PWP vs Total stress : PPC Ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 1
9.80 Metres
15 Sep 14
RESULTS:
Onset of excess pwp :
Total pressure (kPa)
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
Pore water pressure (kPa)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190

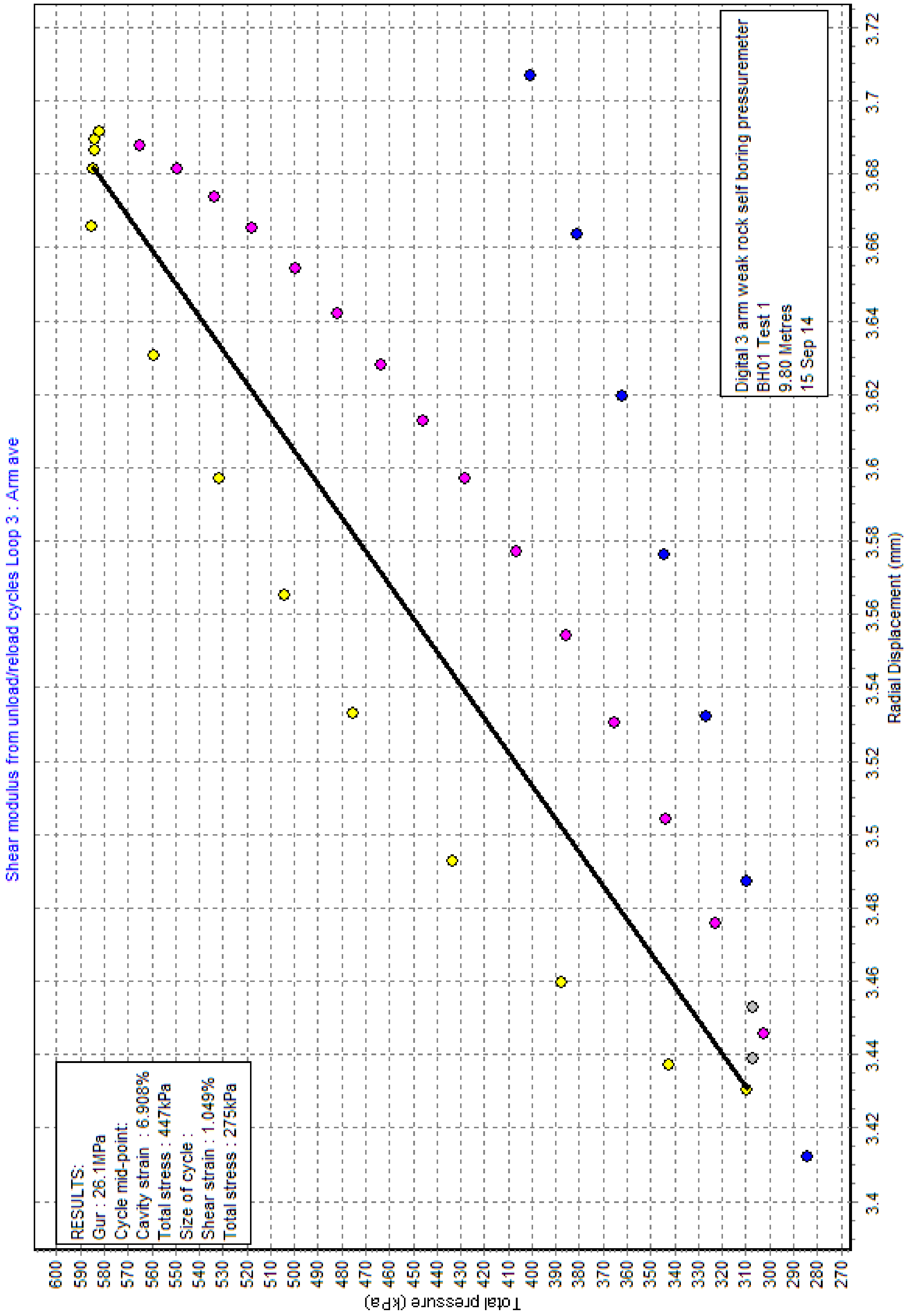

Gibson and Anderson (1961) : Arm ave
RESULTS:
Cu : 153.2kPa
Pl : 1209kPa
Ir : 235
G : 36.0MPa
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 1
9.80 Metres
15 Sep 14
Total pressure (kPa)
940
920
900
880
860
840
820
800
780
760
740
720
700
680
660
640
620
600
580
560
540
520
Ln[shear strain]
-2
-3
-4
-5

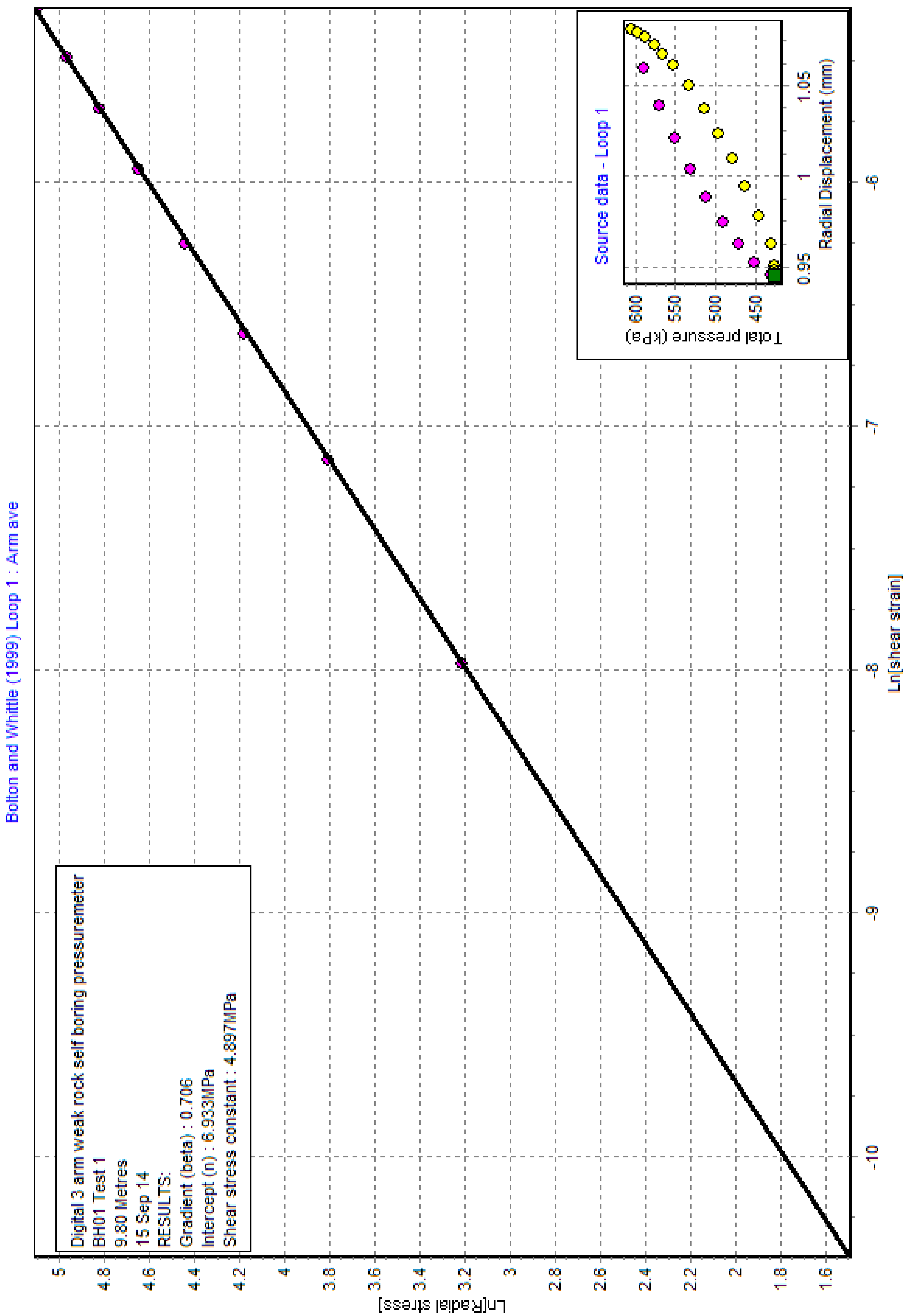

RESULTS:
Cu : 150.9kPa
Jefferies (1988) : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 1
9.80 Metres
15 Sep 14
Total pressure (kPa)
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
Ln[shear strain]
-7
-6
-5
-4
-3


Palmer 1972 (expansion) : Arm ave
RESULTS:
Cu : 153.2kPa
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 1
9.80 Metres
15 Sep 14
Shear strain (%)
1
2
3
4
5
6
7
8
9
10
11
12
Shear stress (kPa)
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30

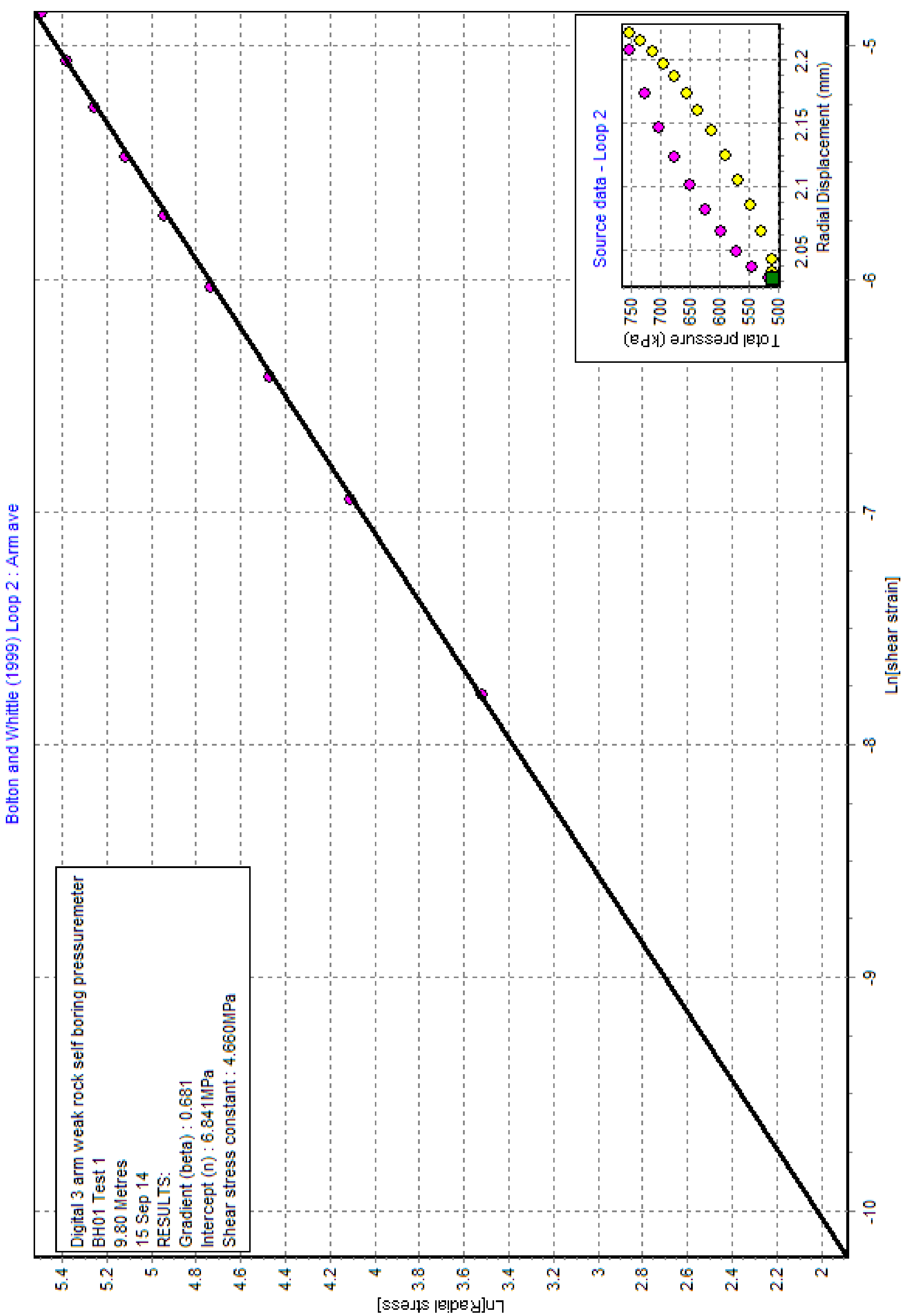

Shear modulus from unload/reload cycles Loop 1 : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 1
9.80 Metres
15 Sep 14
RESULTS:
Gur : 30.1MPa
Cycle mid-point:
Cavity strain : 1.200%
Total stress : 515kPa
Size of cycle :
Shear strain : 0.594%
Total stress : 179kPa
Radial Displacement (mm)
0.9
0.91
0.92
0.93
0.94
0.95
0.96
0.97
0.98
0.99
1
1.01
1.02
1.03
1.04
1.05
1.06
1.07
1.08
1.09
1.1
1.11
1.12
1.13
1.14
1.15
Total pressure (kPa)
630
620
610
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
430
420
410

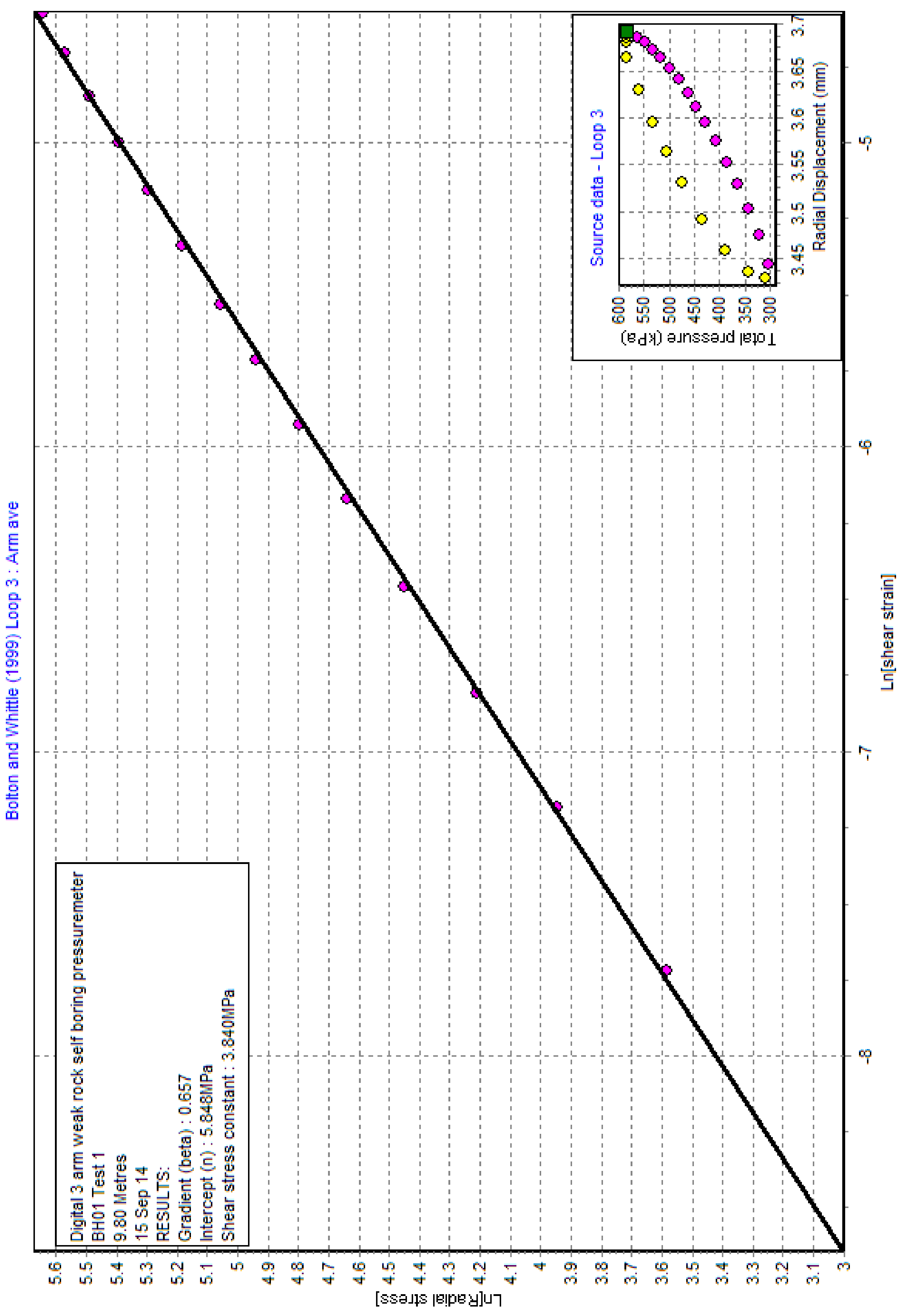

Shear modulus from unload/reload cycles Loop 2 : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 1
9.80 Metres
15 Sep 14
RESULTS:
Gur : 30.1MPa
Cycle mid-point:
Cavity strain : 3.694%
Total stress : 633kPa
Size of cycle :
Shear strain : 0.818%
Total stress : 247kPa
Radial Displacement (mm)
1.98
2
2.02
2.04
2.06
2.08
2.1
2.12
2.14
2.16
2.18
2.2
2.22
2.24
2.26
Total pressure (kPa)
790
780
770
760
750
740
730
720
710
700
690
680
670
660
650
640
630
620
610
600
590
580
570
560
550
540
530
520
510
500
490

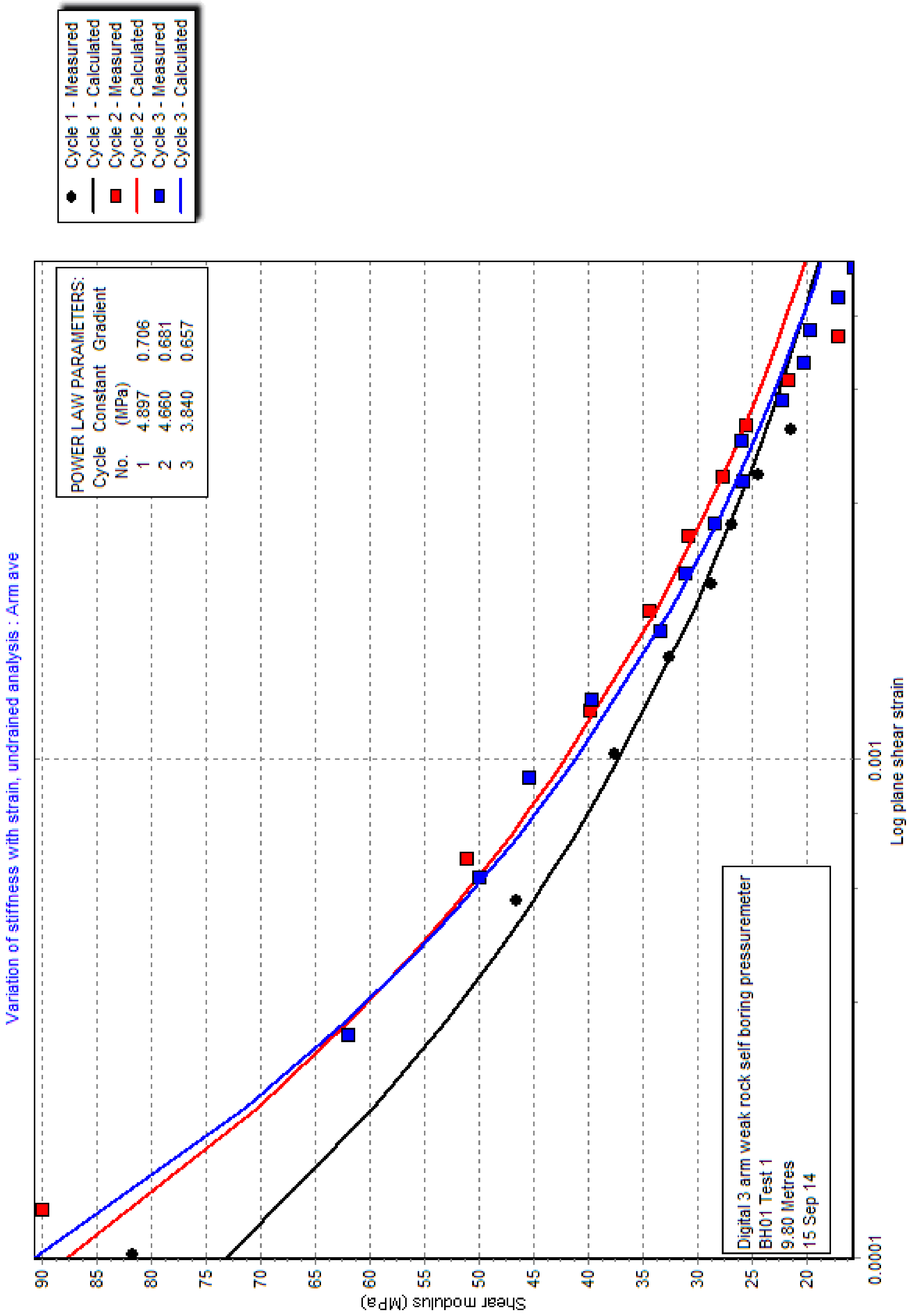

Shear modulus from unload/reload cycles Loop 3 : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 1
9.80 Metres
15 Sep 14
RESULTS:
Gur : 26.1MPa
Cycle mid-point:
Cavity strain : 6.908%
Total stress : 447kPa
Size of cycle :
Shear strain : 1.049%
Total stress : 275kPa
Radial Displacement (mm)
3.4
3.42
3.44
3.46
3.48
3.5
3.52
3.54
3.56
3.58
3.6
3.62
3.64
3.66
3.68
3.7
3.72
Total pressure (kPa)
600
590
580
570
560
550
540
530
520
510
500
490
480
470
460
450
440
430
420
410
400
390
380
370
360
350
340
330
320
310
300
290
280
270

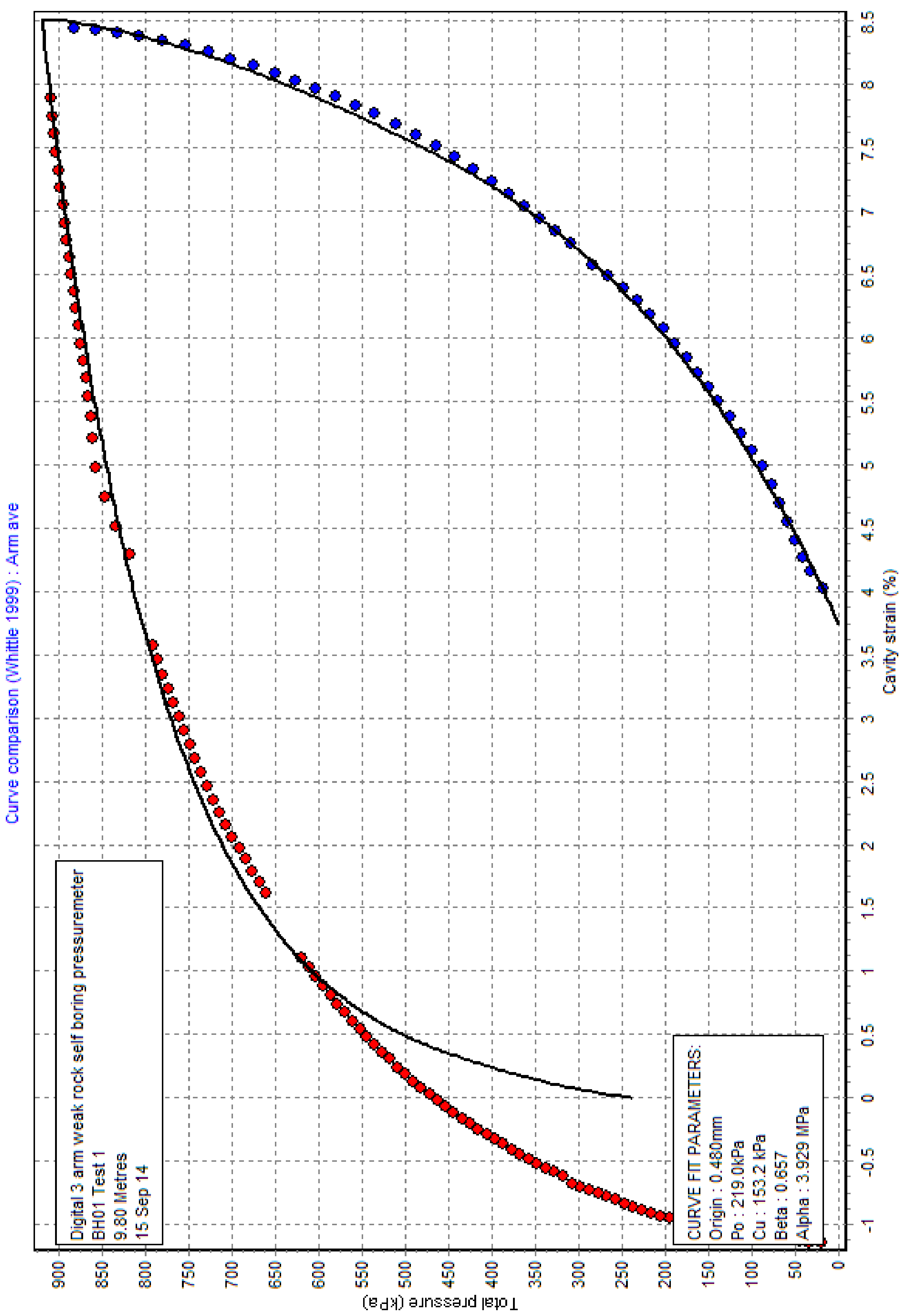


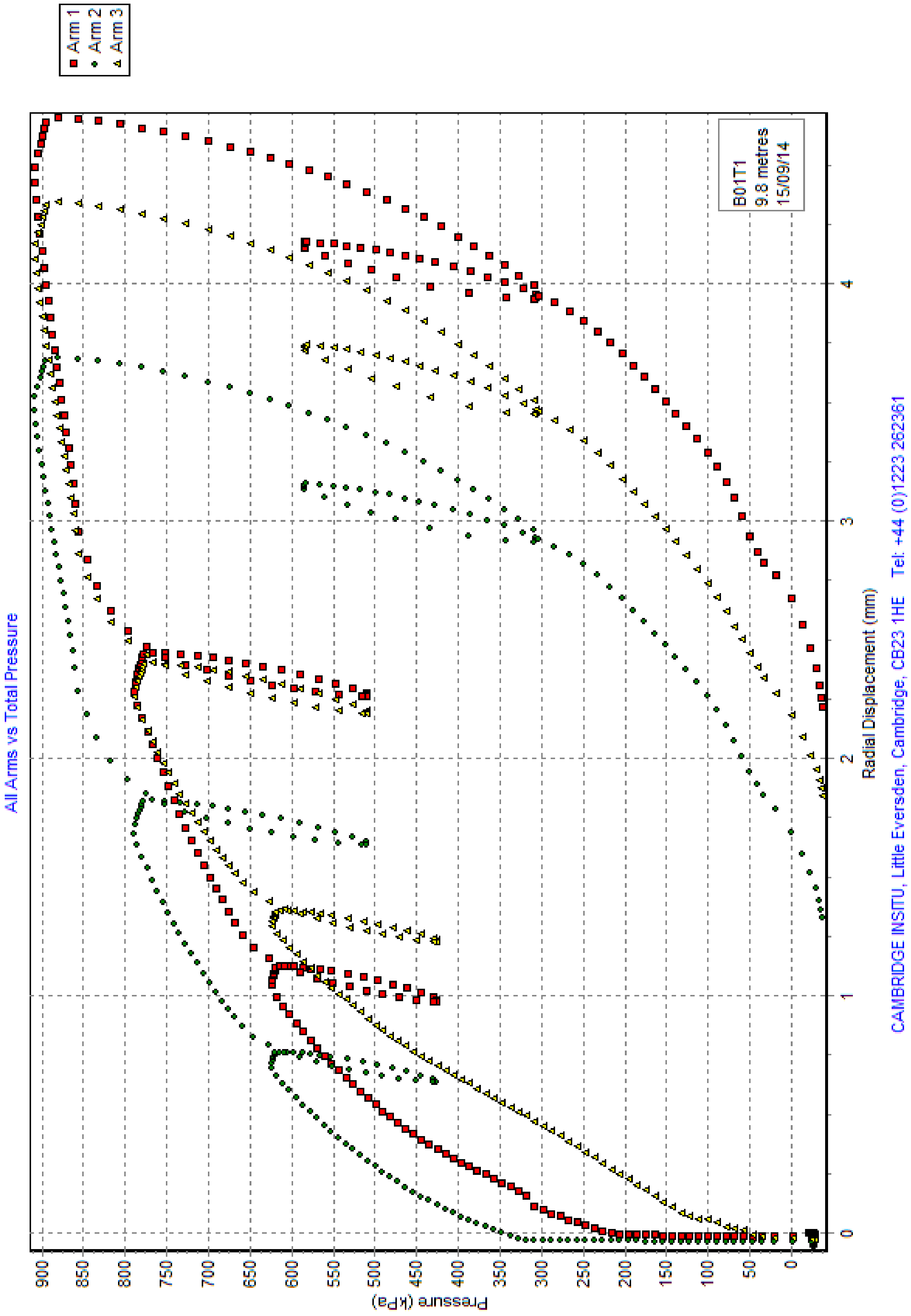
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 1
9.80 Metres
15 Sep 14
RESULTS:
Gradient (beta) : 0.706
Intercept (n) : 6.933MPa
Shear stress constant : 4.897MPa


Bolton and Whittle (1999) Loop 2 : Arm ave
Ln[Radial stress]
5.4
5.2
5
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
Ln[shear strain]
-5
-6
-7
-8
-9
-10
Source data - Loop 2
Total pressure (kPa)
750
700
650
600
550
500
Radial Displacement (mm)
2.05
2.1
2.15
2.2
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 1
9.80 Metres
15 Sep 14
RESULTS:
Gradient (beta) : 0.681
Intercept (n) : 6.841MPa
Shear stress constant : 4.660MPa


Bolton and Whittle (1999) Loop 3 : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 1
9.80 Metres
15 Sep 14
RESULTS:
Gradient (beta) : 0.657
Intercept (n) : 5.848MPa
Shear stress constant : 3.840MPa
Ln[Radial stress]
5.6
5.5
5.4
5.3
5.2
5.1
5
4.9
4.8
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
Ln[shear strain]
-5
-6
-7
-8
Source data - Loop 3
Total pressure (kPa)
600
550
500
450
400
350
300
Radial Displacement (mm)
3.45
3.5
3.55
3.6
3.65
3.7


Variation of stiffness with strain, undrained analysis : Arm ave
Cycle 1 - Measured
Cycle 1 - Calculated
Cycle 2 - Measured
Cycle 2 - Calculated
Cycle 3 - Measured
Cycle 3 - Calculated
POWER LAW PARAMETERS:
Cycle No. Constant (MPa) Gradient
1 4.897 0.706
2 4.660 0.681
3 3.840 0.657
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 1
9.80 Metres
15 Sep 14
Shear modulus (MPa)
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
0.0001
0.001
Log plane shear strain


Curve comparison (Whittle 1999) : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 1
9.80 Metres
15 Sep 14
CURVE FIT PARAMETERS:
Origin : 0.480mm
Po : 219.0kPa
Cu : 153.2 kPa
Beta : 0.657
Alpha : 3.929 MPa
Total pressure (kPa)
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Cavity strain (%)
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1


All Arms vs Total Pressure
■ Arm 1
● Arm 2
▲ Arm 3
B01T1
9.8 metres
15/09/14
Pressure (kPa)
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Radial Displacement (mm)
0
1
2
3
4
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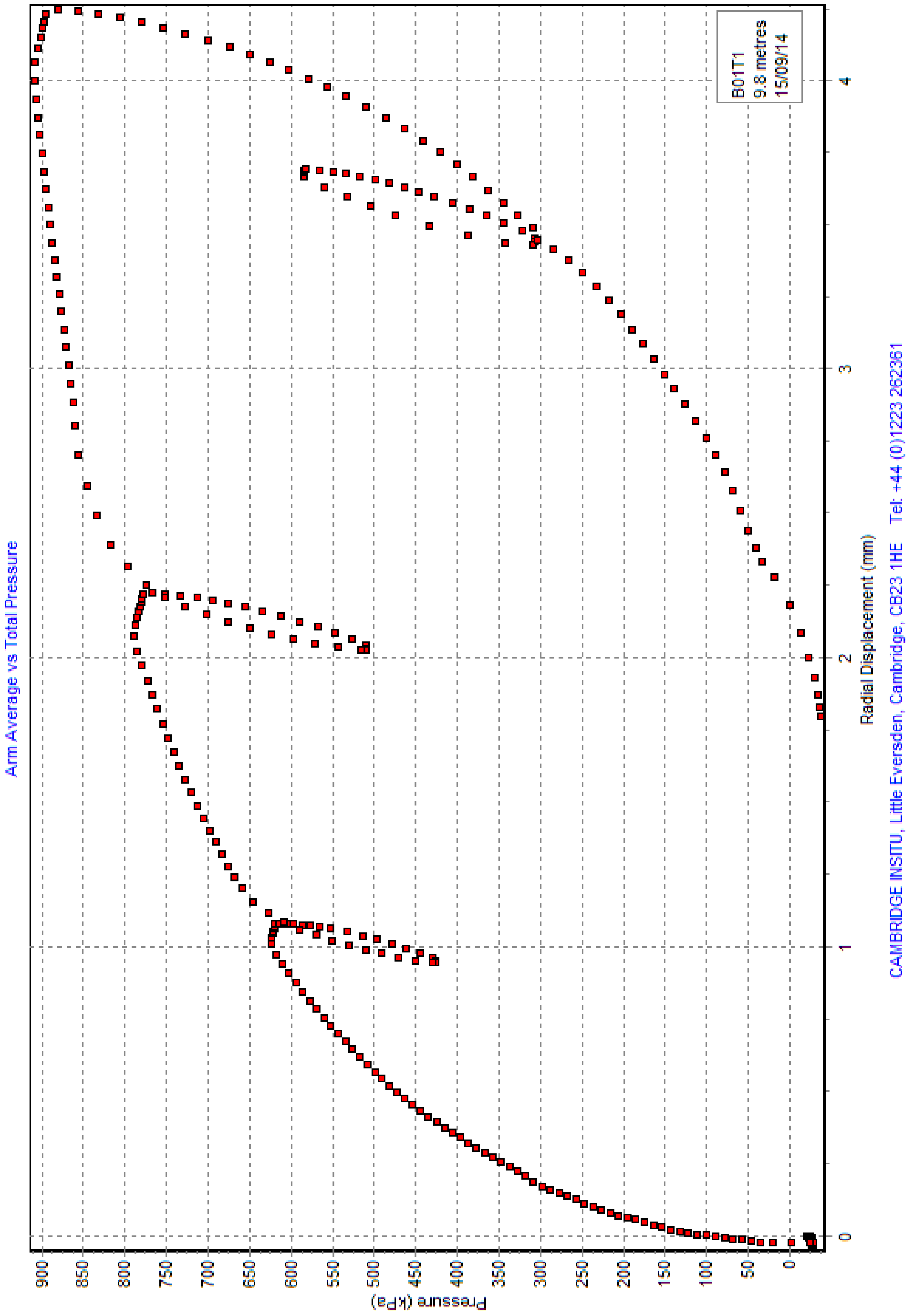
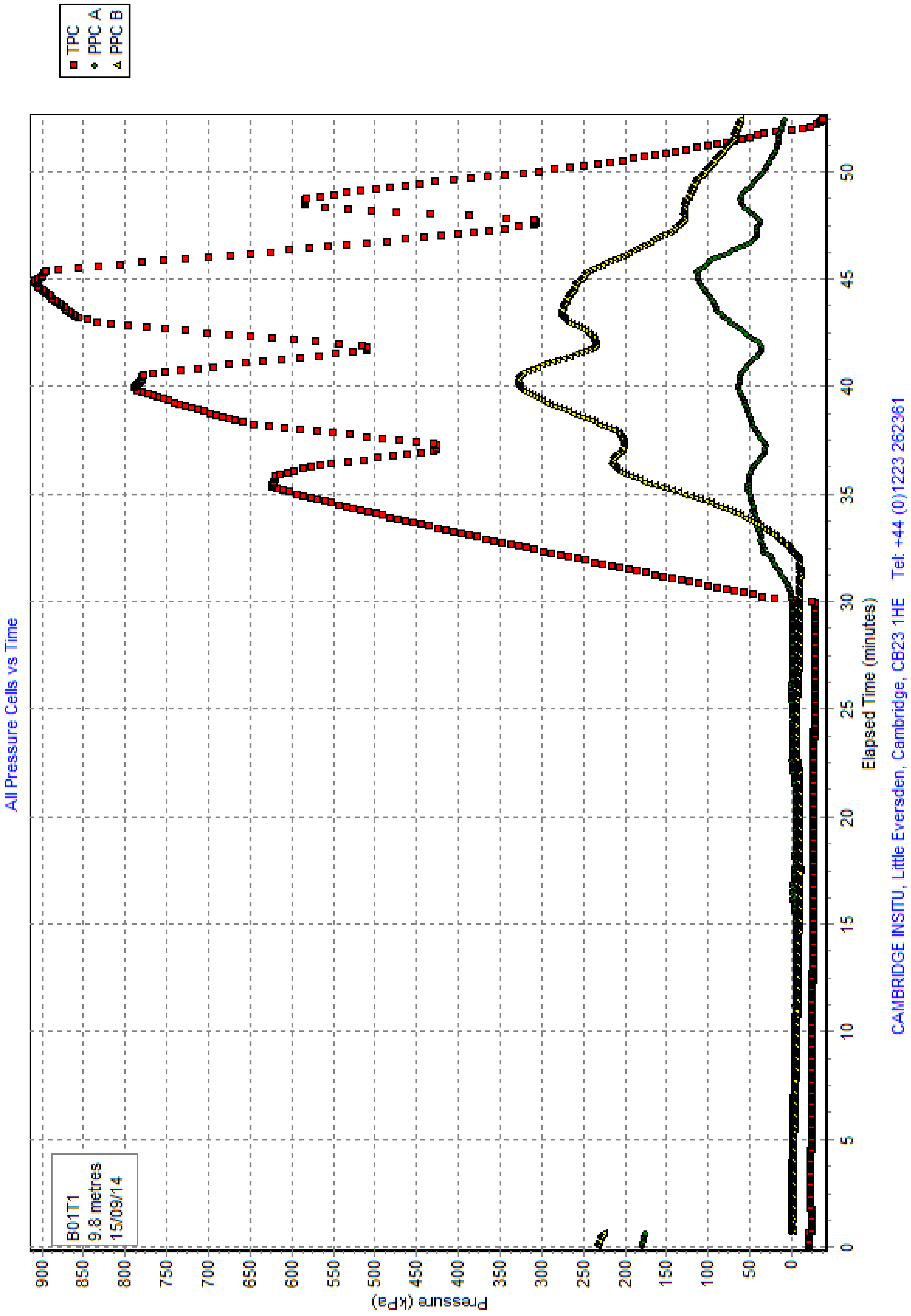
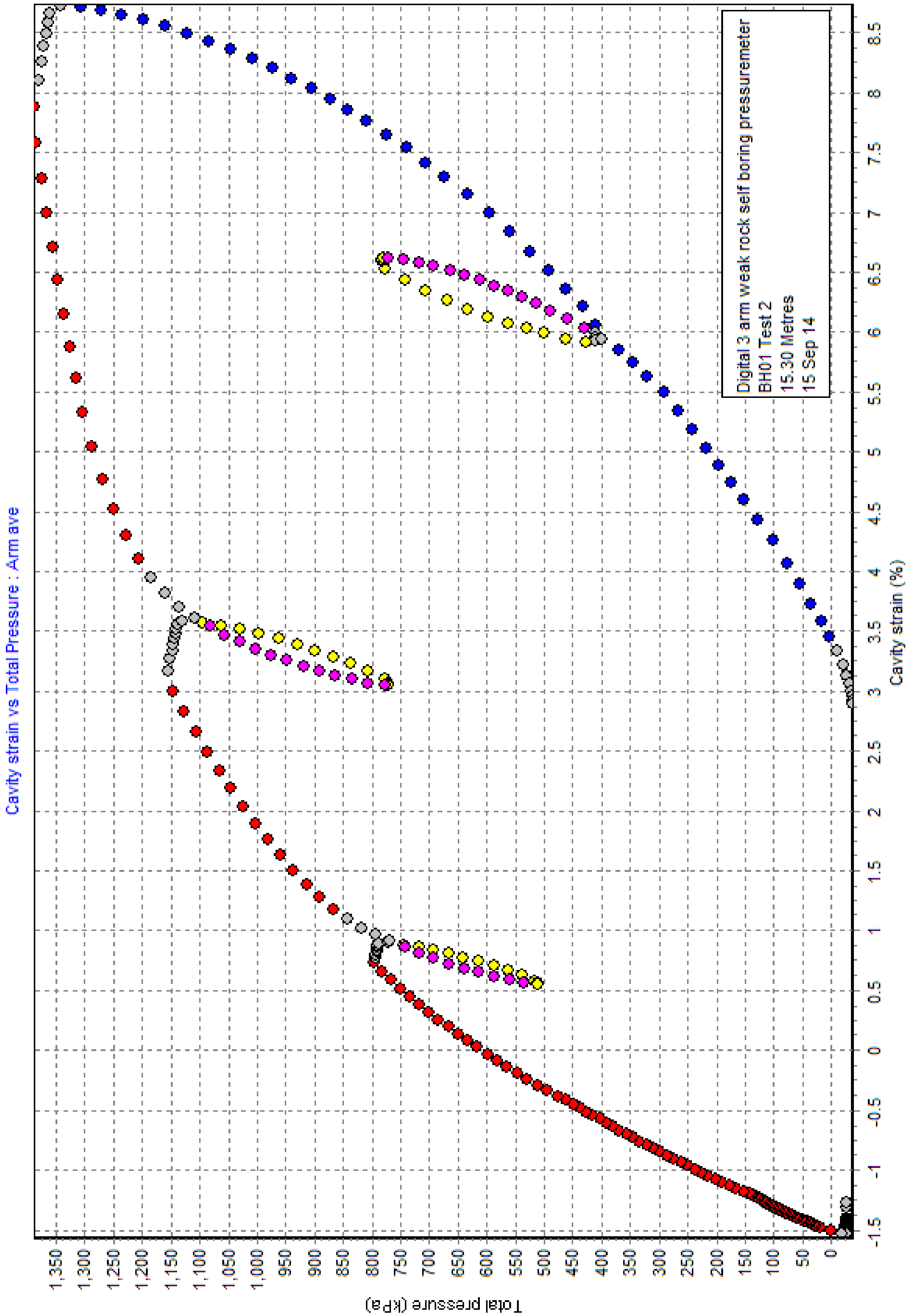
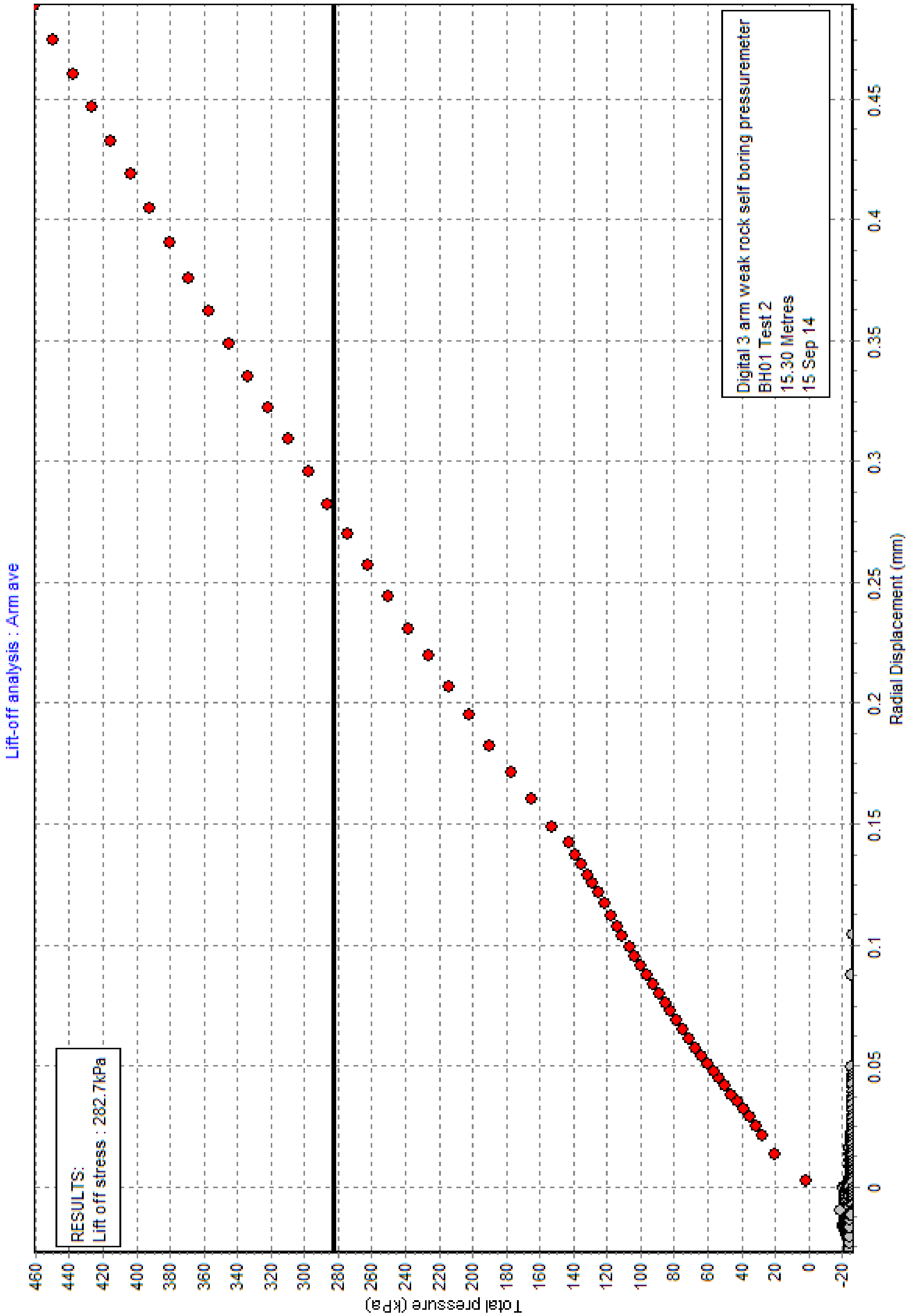
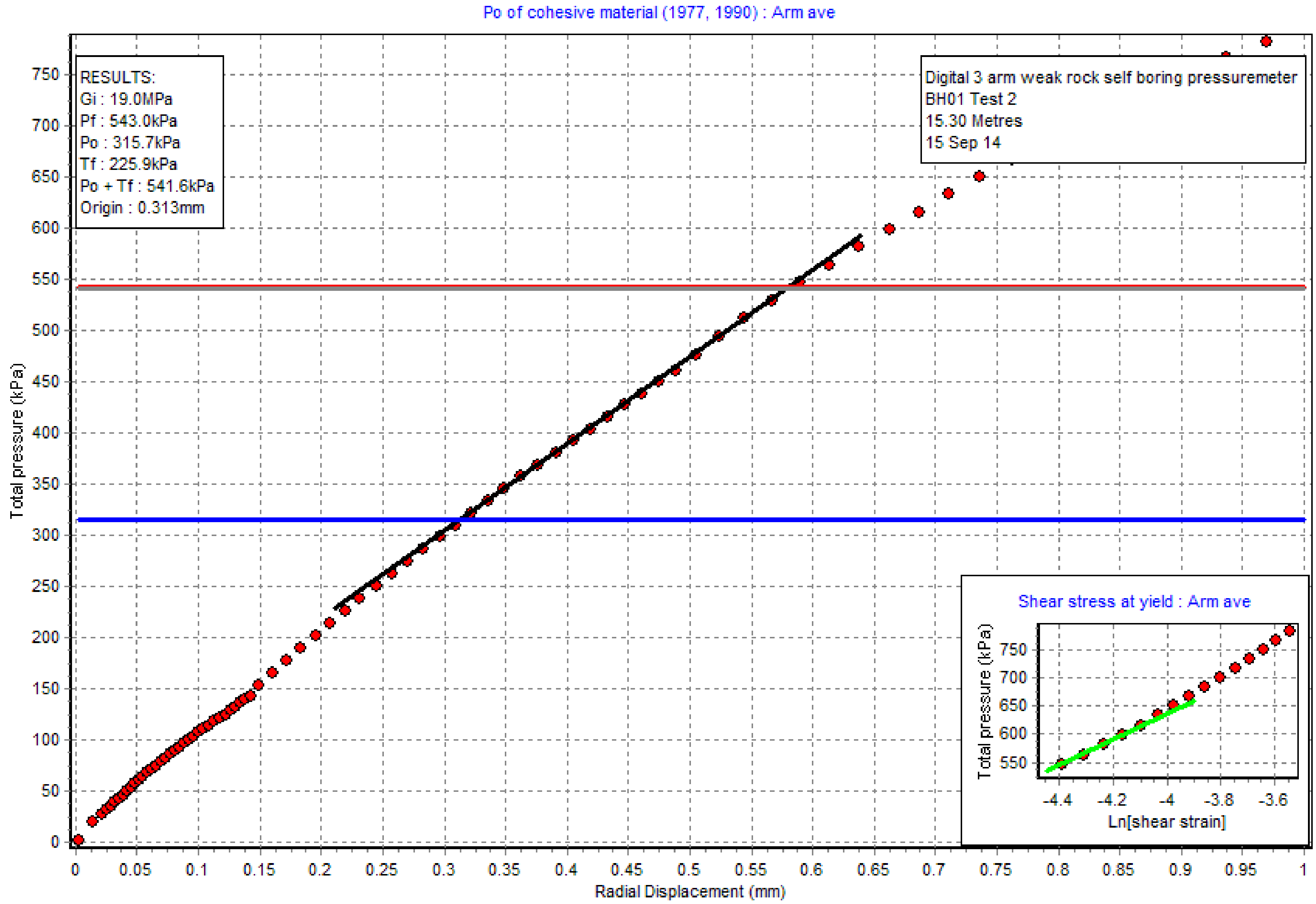

Arm Average vs Total Pressure
Pressure (kPa)
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Radial Displacement (mm)
0
1
2
3
4
B01T1
9.8 metres
15/09/14
CAMBRIDGE INSITU, Little Eversden, Cambridge, CB23 1HE Tel: +44 (0)1223 262361

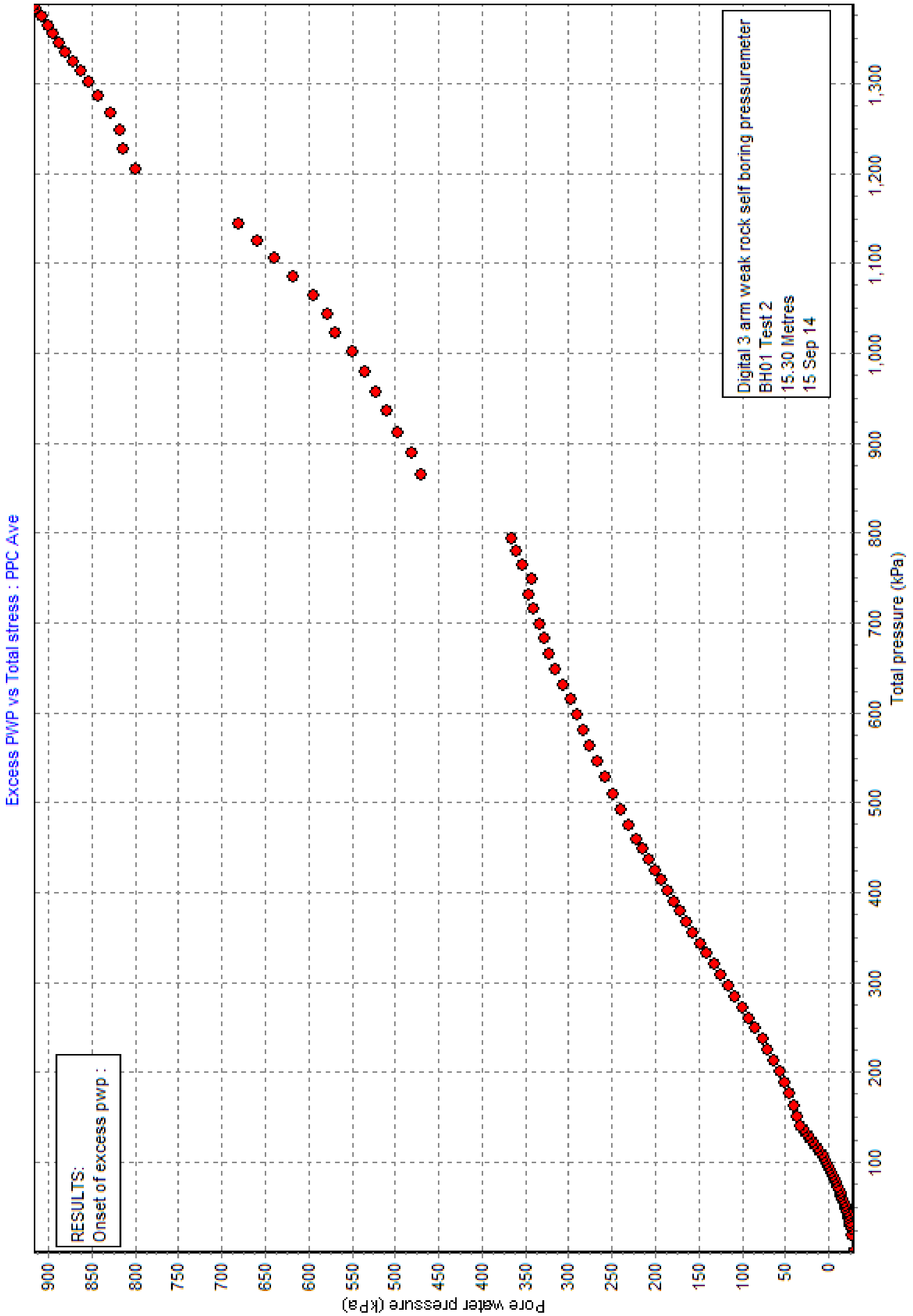

All Pressure Cells vs Time
■ TPC
● PPC A
▵ PPC B
B01T1
9.8 metres
15/09/14
Pressure (kPa)
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Elapsed Time (minutes)
0
5
10
15
20
25
30
35
40
45
50
CAMBRIDGE INSITU, Little Eversden, Cambridge, CB23 1HE Tel: +44 (0)1223 262361

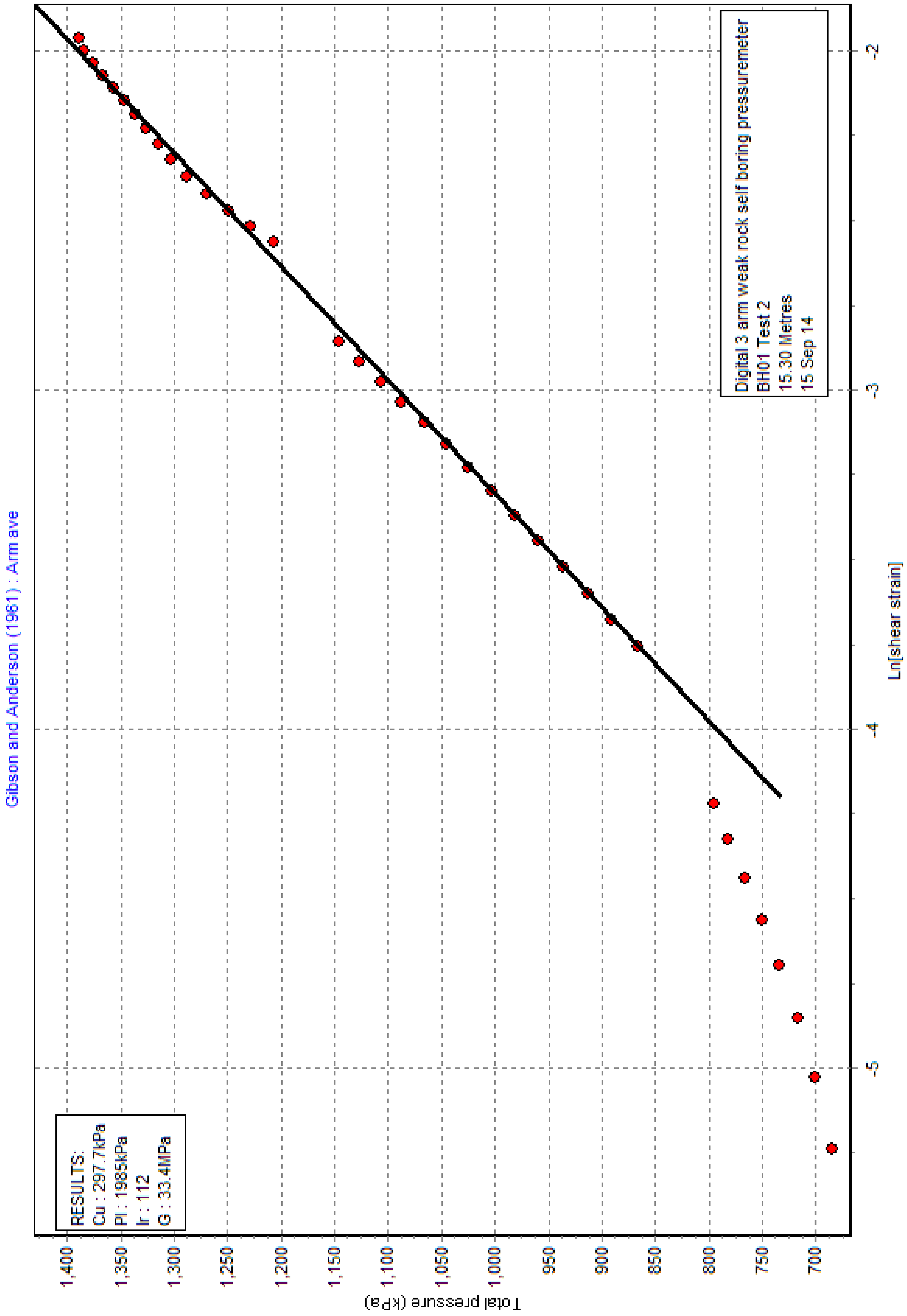
```
BH01 Test 2 - SUMMARY OF RESULTS
[File made with WinSitu  Version 3.6.1.1]

[DETAILS OF TEST]
Project        :
Site           :   1 Bedford Avenue
Borehole       :   BH01
Test name      :   BH01 Test 2
Test date      :   15 Sep 14
Test depth     :   15.30 Metres
Water table    :   Nothing entered
Ambient PWP    :   0.0 kPa
Material       :   London Clay
Probe          :   Digital 3 arm weak rock self boring pressuremeter
Diameter       :   88.1 mm
Data analysed using average arm displacement curve
A non-linear analysis of the rebound cycles has been carried out
The file includes results from a curve fitting analysis

Analysed by SDB on 14 Oct 14

Remarks:

[RESULTS FOR CAVITY REFERENCE PRESSURE]
Strain Origin (mm)                  :   "Arm ave=0.670"
Po from Marsland & Randolph (kPa)   :   "Arm ave=315.7"
Po from Lift off (kPa)              :   "Arm ave=282.7"
Best estimate of Po (kPa)           :   "Arm ave=282.0"

[UNDRAINED STRENGTH PARAMETERS]
Gibson & Anderson 1961 - Cu (kPa)   :   "Arm ave=297.7"
Limit pressure (kPa)                :   "Arm ave=1985"
Jefferies 1988 - Cu (kPa)           :   "Arm ave=296.7"
Undrained yield stress (kPa)        :   "Arm ave=543.0"

[LINEAR INTERPRETATION OF SHEAR MODULUS G]
Initial slope shear modulus (MPa) :"Arm ave=19.0"
Axis       Loop   Value    Mean Strain  Mean Pc  dE      dPc
           No     (MPa)    (%)          (kPa)    (%)     (kPa)
Arm ave    1      36.6     0.725        629      0.651   239
Arm ave    2      32.2     3.324        934      1.005   326
Arm ave    3      28.9     6.284        597      1.278   372

[UNDRAINED NON LINEAR INTERPRETATION OF SECANT SHEAR MODULUS]
Axis       Loop   Intercept  Alpha      Gradient
           No     (MPa)      (MPa)
Arm ave    1      10.056     7.441      0.740
Arm ave    2      8.872      6.322      0.713
Arm ave    3      7.582      5.133      0.677


[PARAMETERS USED FOR UNDRAINED CURVE MODELLING]
{Axis is  Arm ave}
Strain Origin (mm)                  :   0.67
Po (kPa)                            :   282
Cu (kPa)                            :   297.7
Limit pressure (kPa)                :   1985
Non-linear exponent                 :   0.677
Calculated alpha (MPa)              :   5.259
G at yield (MPa)                    :   20.7
```

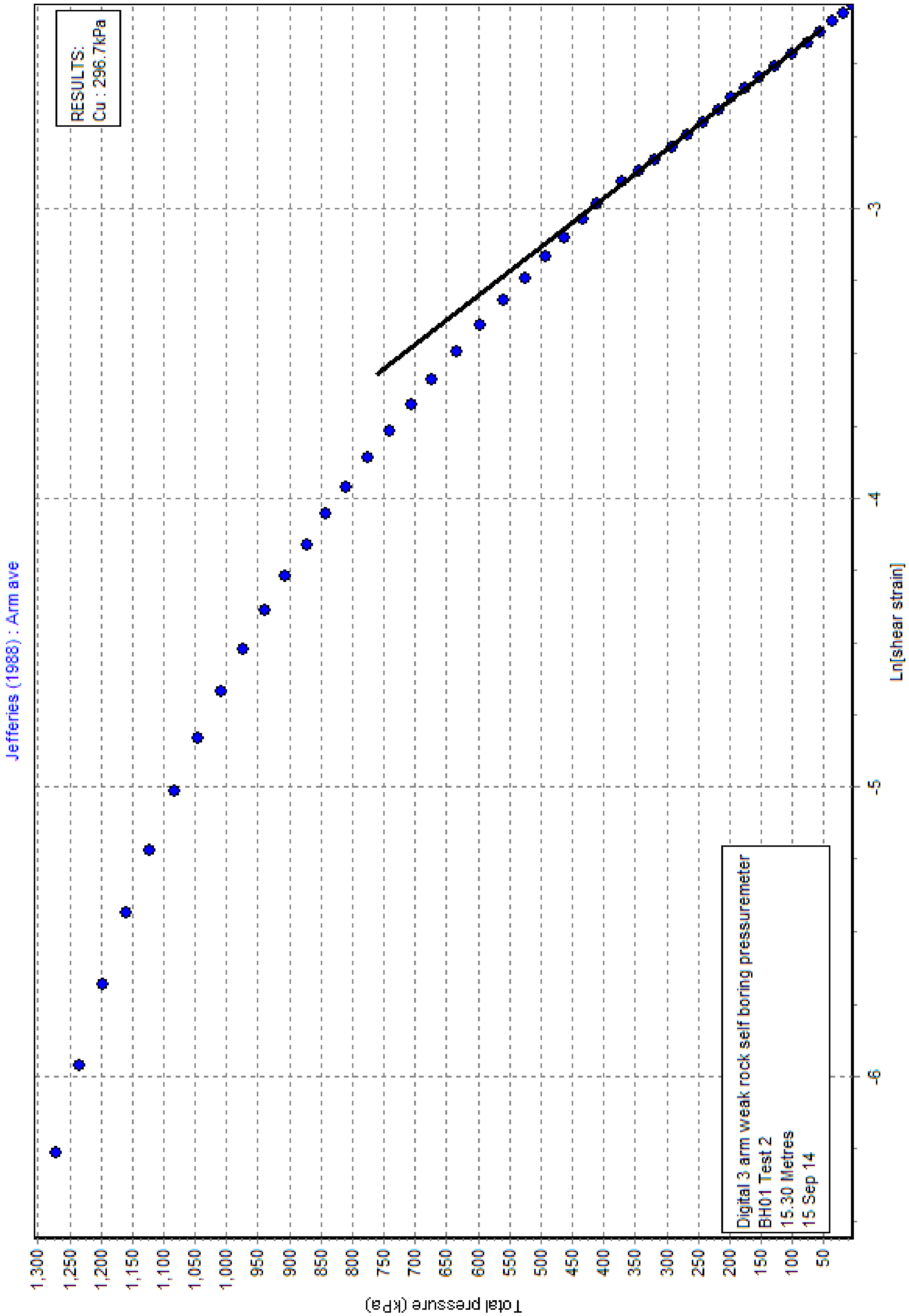

Cavity strain vs Total Pressure : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 2
15.30 Metres
15 Sep 14
Cavity strain (%)
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
Total pressure (kPa)
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1,000
1,050
1,100
1,150
1,200
1,250
1,300
1,350

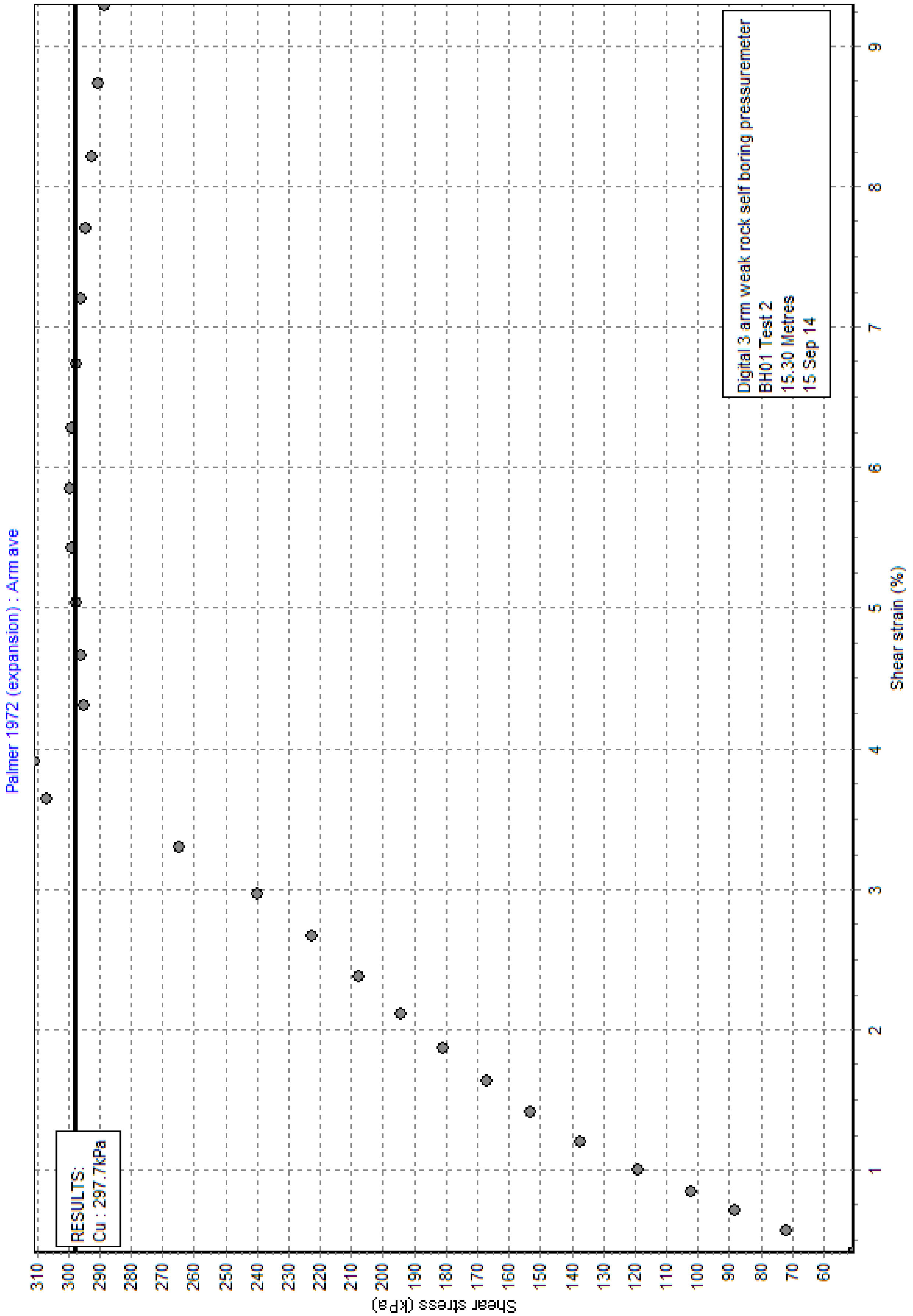

Lift-off analysis : Arm ave
RESULTS:
Lift off stress : 282.7kPa
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 2
15.30 Metres
15 Sep 14
Total pressure (kPa)
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
Radial Displacement (mm)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45

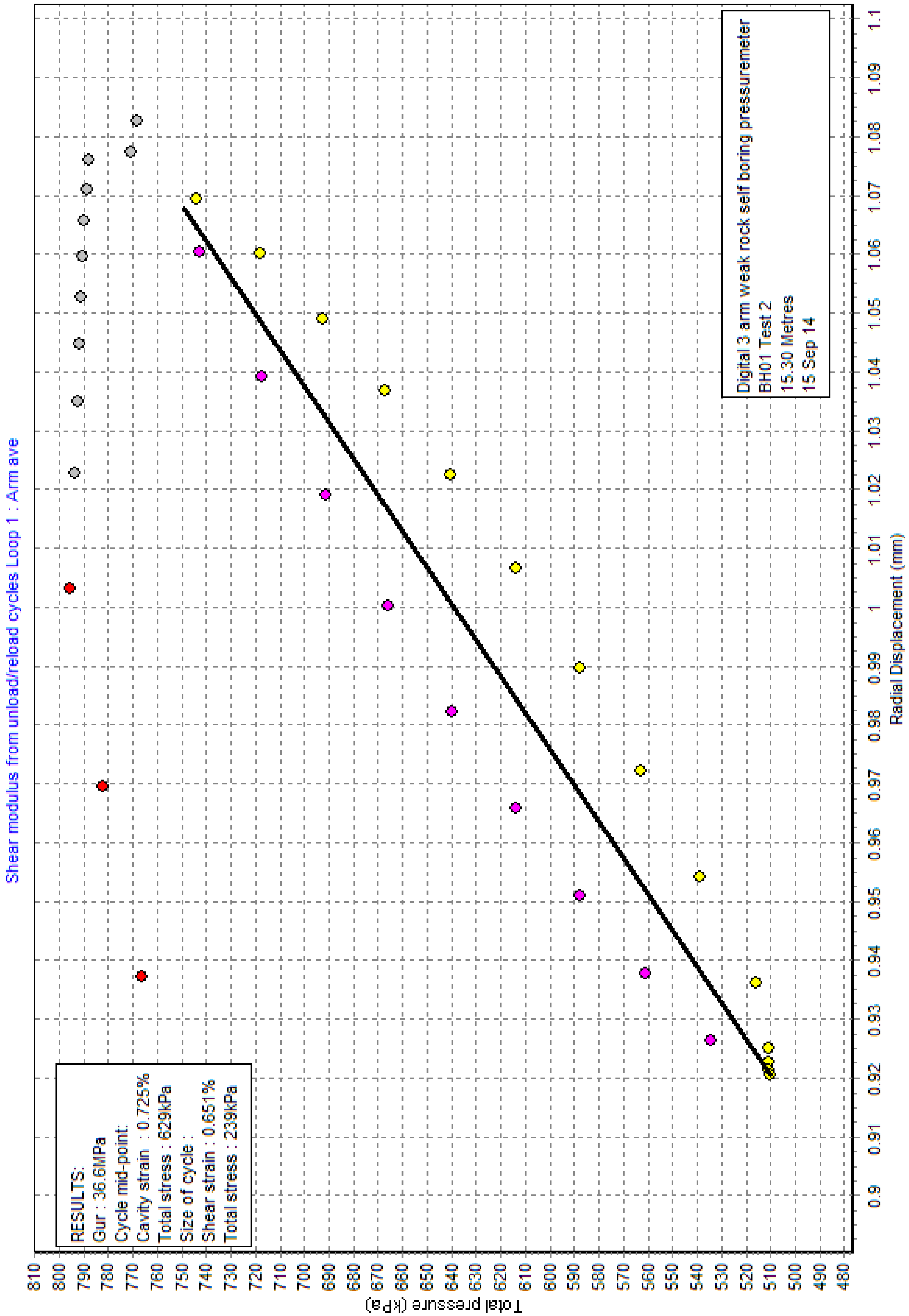

Po of cohesive material (1977, 1990) : Arm ave
RESULTS:
Gi : 19.0MPa
Pf : 543.0kPa
Po : 315.7kPa
Tf : 225.9kPa
Po + Tf : 541.6kPa
Origin : 0.313mm
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 2
15.30 Metres
15 Sep 14
Total pressure (kPa)
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Radial Displacement (mm)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
Shear stress at yield : Arm ave
Total pressure (kPa)
750
700
650
600
550
Ln[shear strain]
-4.4
-4.2
-4
-3.8
-3.6


Excess PWP vs Total stress : PPC Ave
RESULTS:
Onset of excess pwp :
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 2
15.30 Metres
15 Sep 14
Pore water pressure (kPa)
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Total pressure (kPa)
100
200
300
400
500
600
700
800
900
1,000
1,100
1,200
1,300

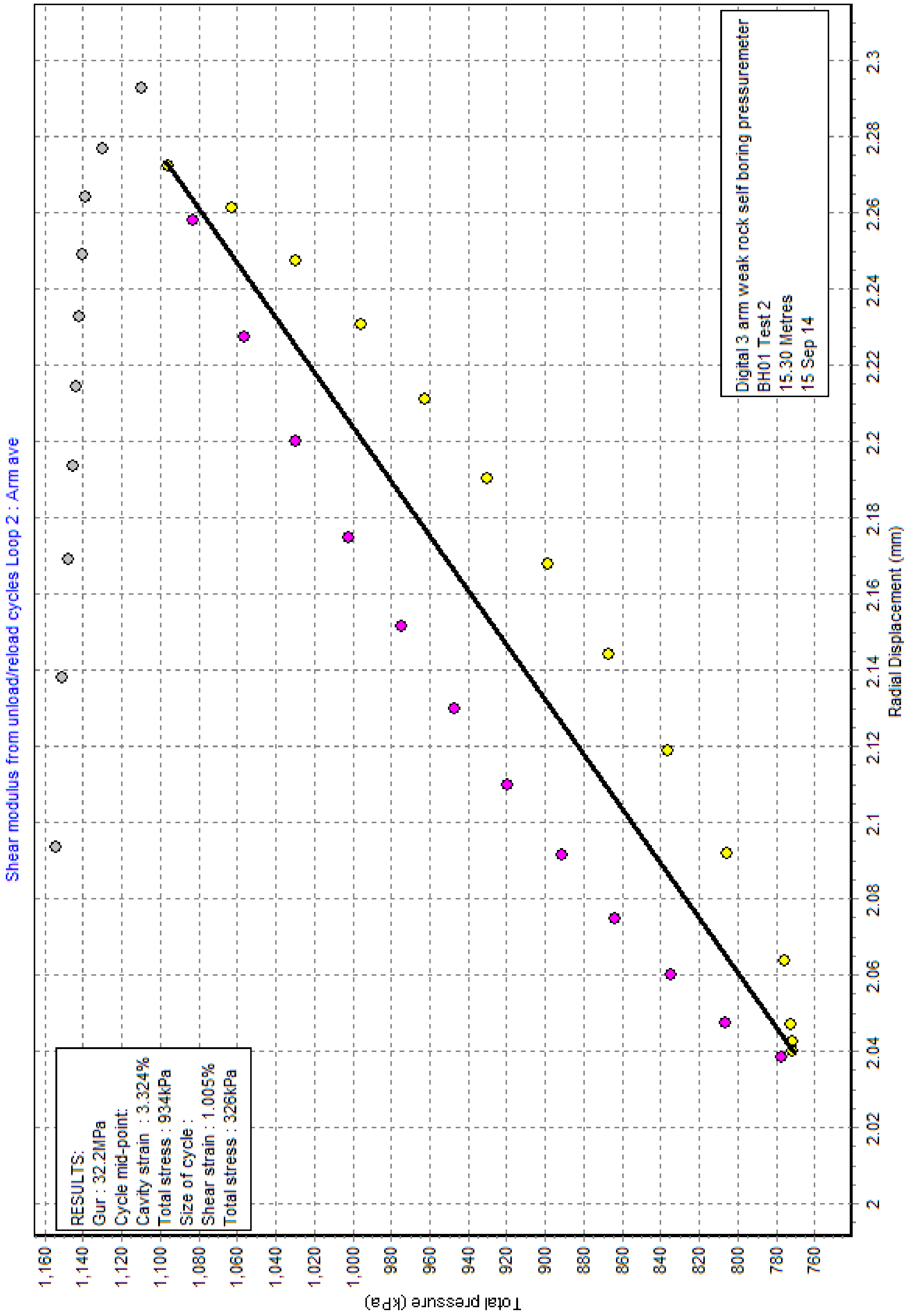

Gibson and Anderson (1961) : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 2
15.30 Metres
15 Sep 14
RESULTS:
Cu : 297.7kPa
Pl : 1985kPa
Ir : 112
G : 33.4MPa
Total pressure (kPa)
Ln[shear strain]
1,400
1,350
1,300
1,250
1,200
1,150
1,100
1,050
1,000
950
900
850
800
750
700
-2
-3
-4
-5

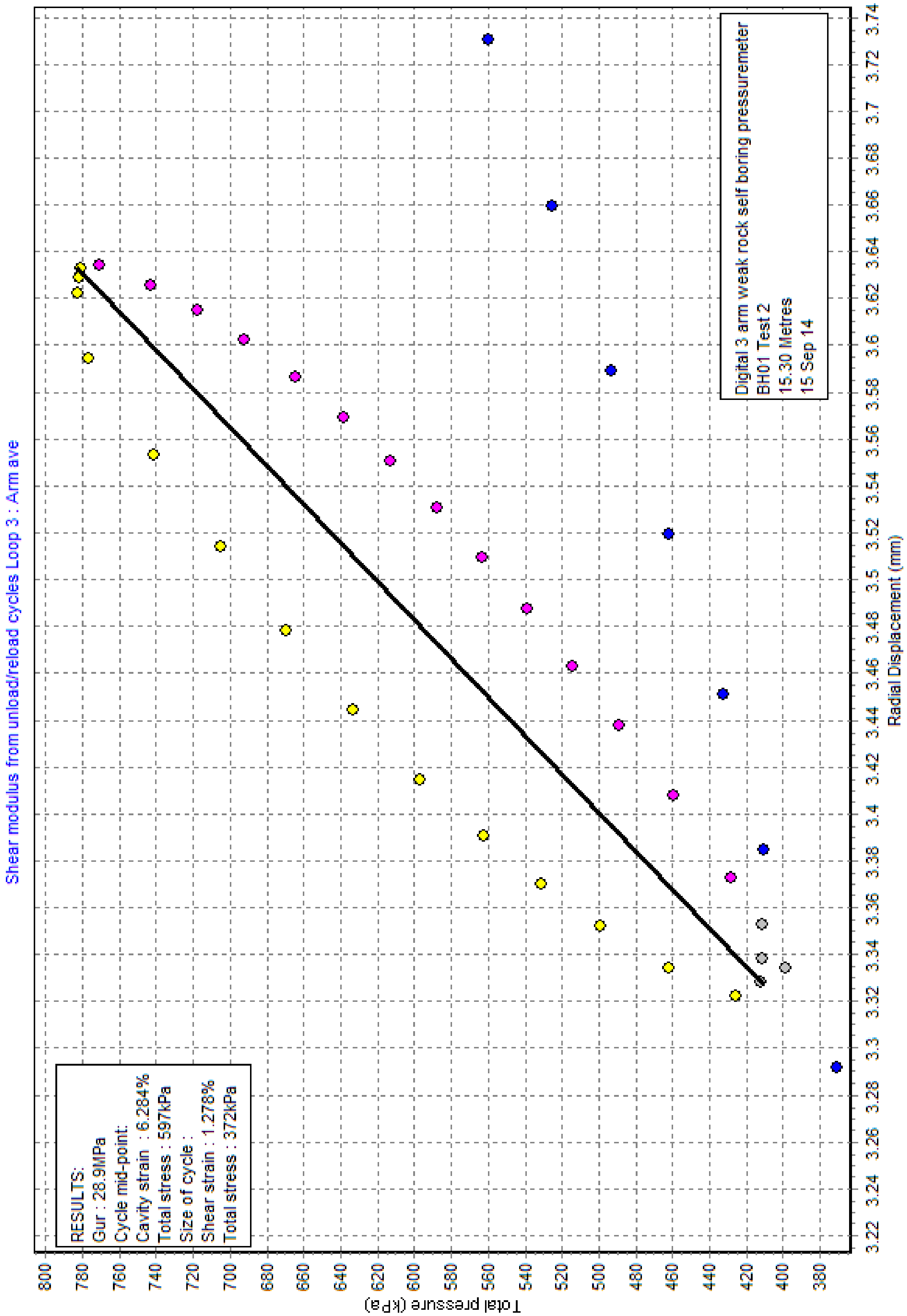

Jefferies (1988) : Arm ave
RESULTS:
Cu : 296.7kPa
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 2
15.30 Metres
15 Sep 14
Ln[shear strain]
-3
-4
-5
-6
Total pressure (kPa)
1,300
1,250
1,200
1,150
1,100
1,050
1,000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50

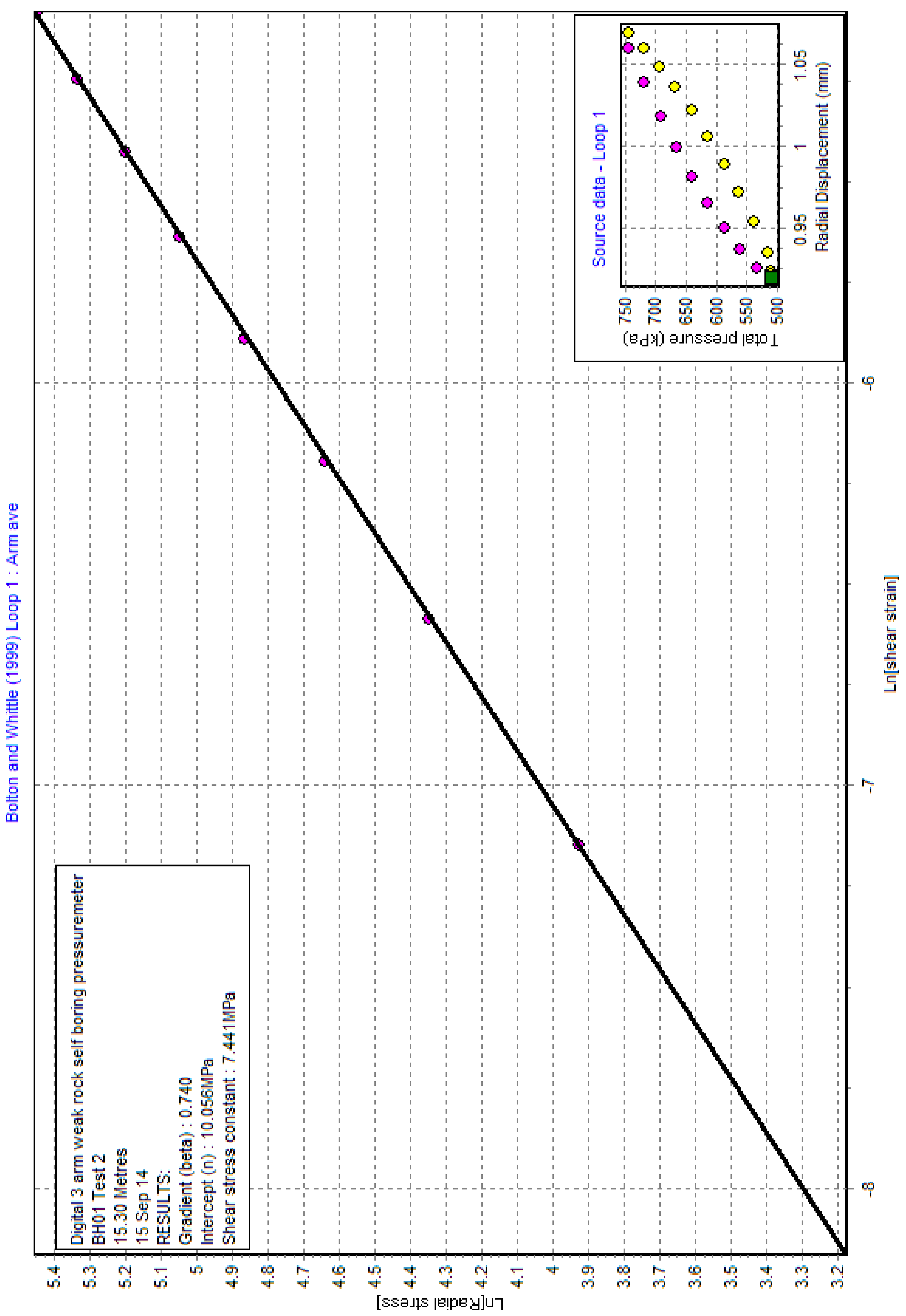

Palmer 1972 (expansion) : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 2
15.30 Metres
15 Sep 14
RESULTS:
Cu : 297.7kPa
Shear stress (kPa)
310
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
Shear strain (%)
1
2
3
4
5
6
7
8
9

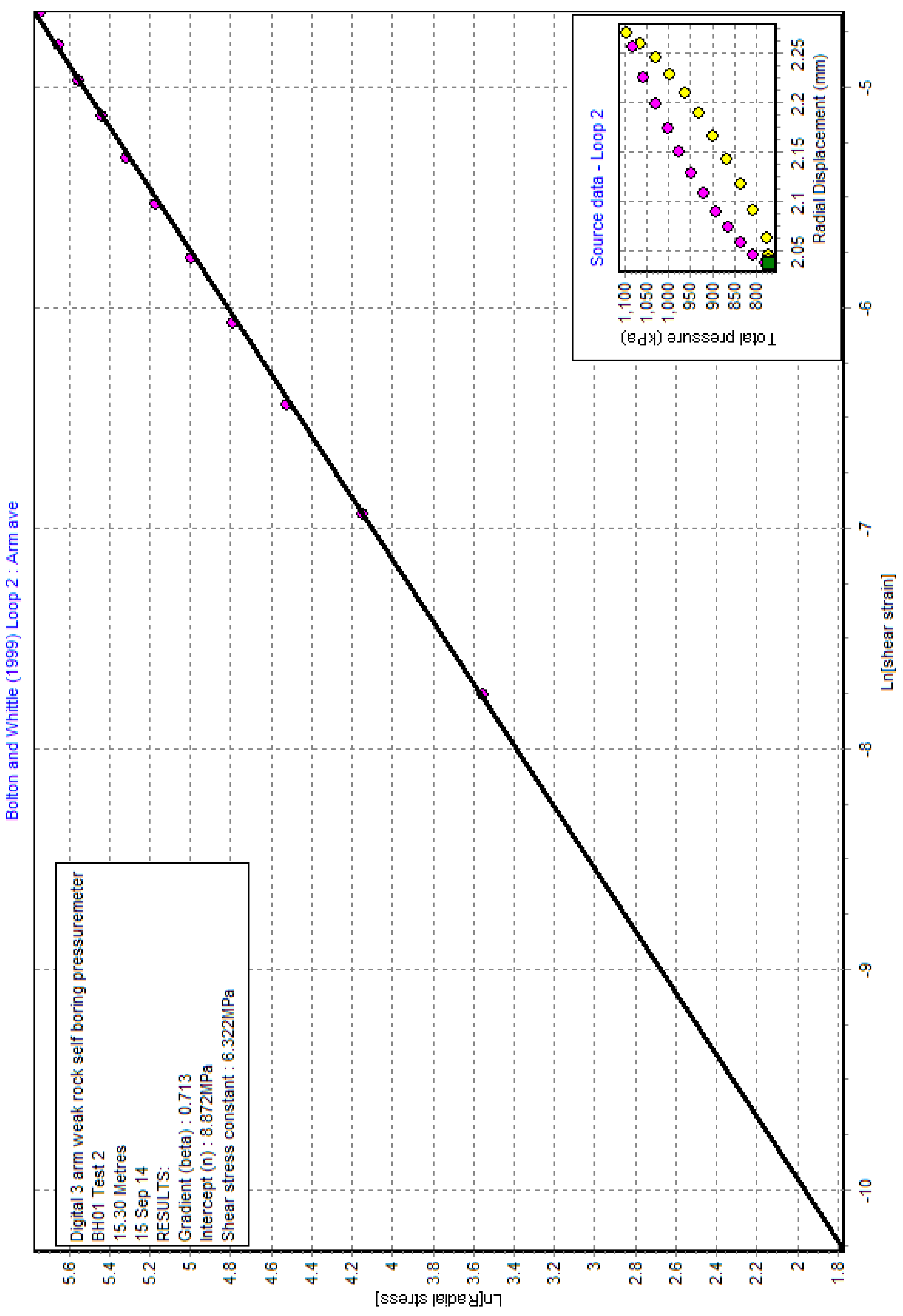


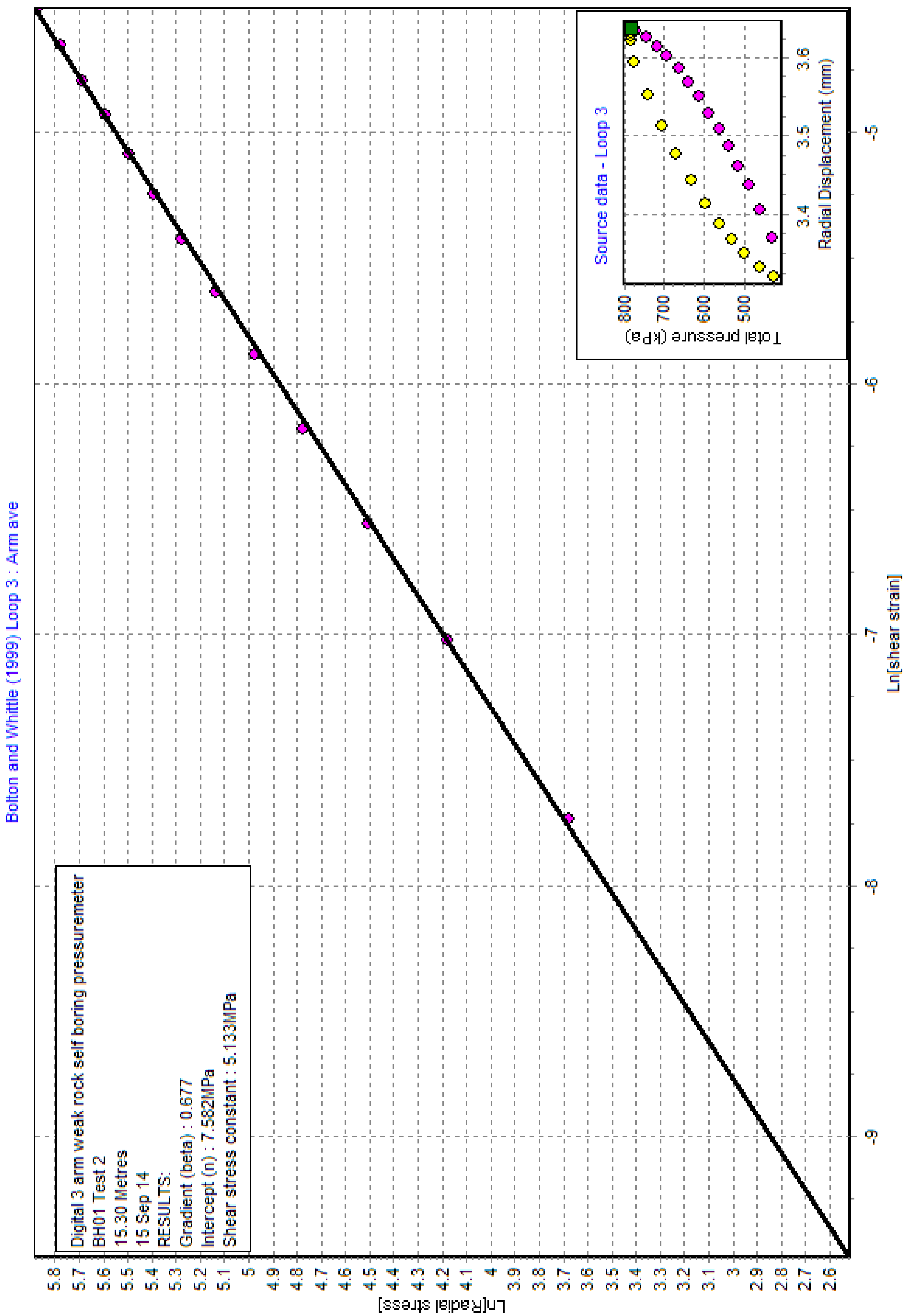
RESULTS:
Gur : 36.6MPa
Cycle mid-point:
Cavity strain : 0.7725%
Total stress : 629kPa
Size of cycle :
Shear strain : 0.651%
Total stress : 239kPa

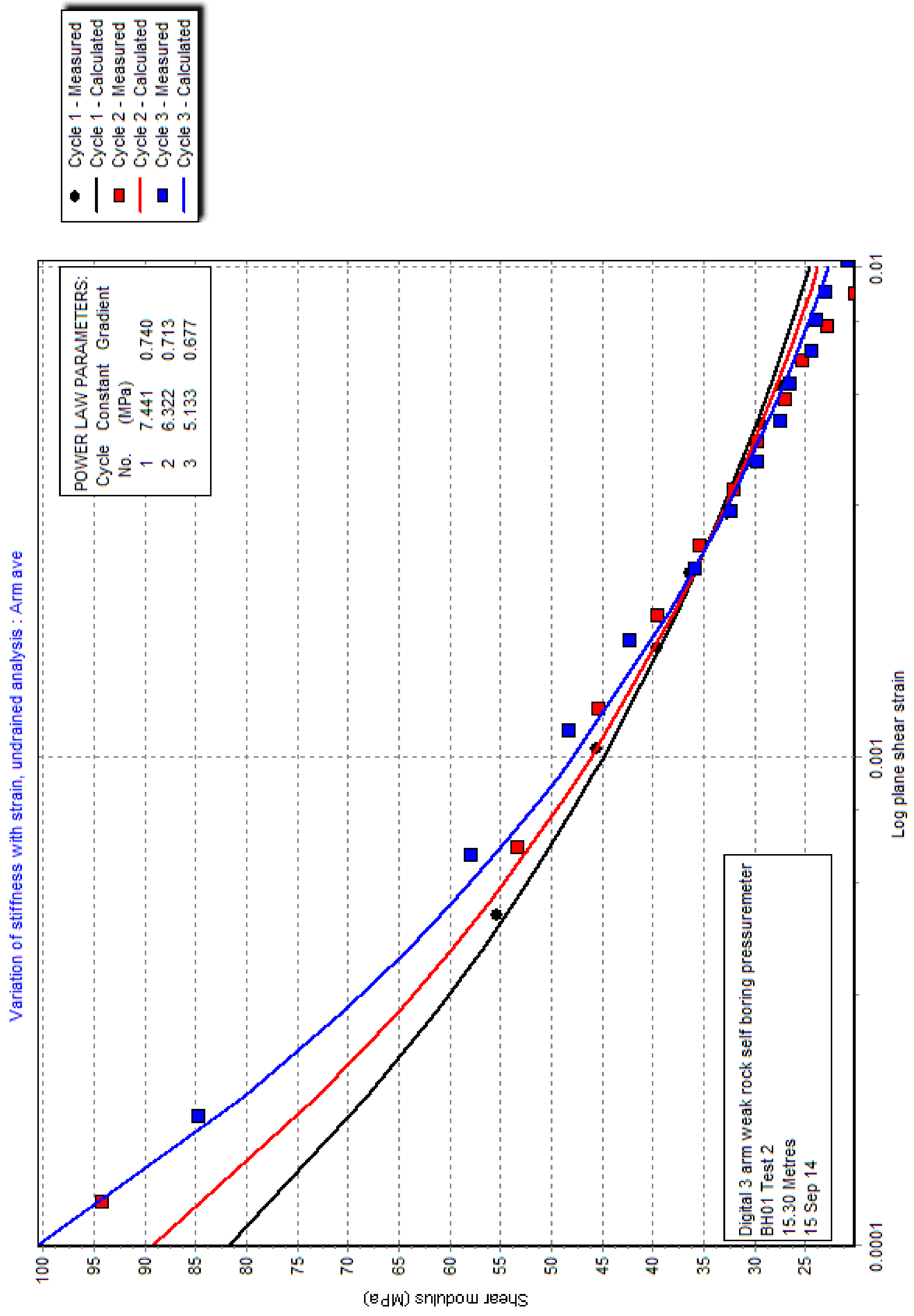

Shear modulus from unload/reload cycles Loop 2 : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 2
15.30 Metres
15 Sep 14
RESULTS:
Gur : 32.2MPa
Cycle mid-point:
Cavity strain : 3.324%
Total stress : 934kPa
Size of cycle :
Shear strain : 1.005%
Total stress : 326kPa
Radial Displacement (mm)
2
2.02
2.04
2.06
2.08
2.1
2.12
2.14
2.16
2.18
2.2
2.22
2.24
2.26
2.28
2.3
Total pressure (kPa)
1,160
1,140
1,120
1,100
1,080
1,060
1,040
1,020
1,000
980
960
940
920
900
880
860
840
820
800
780
760

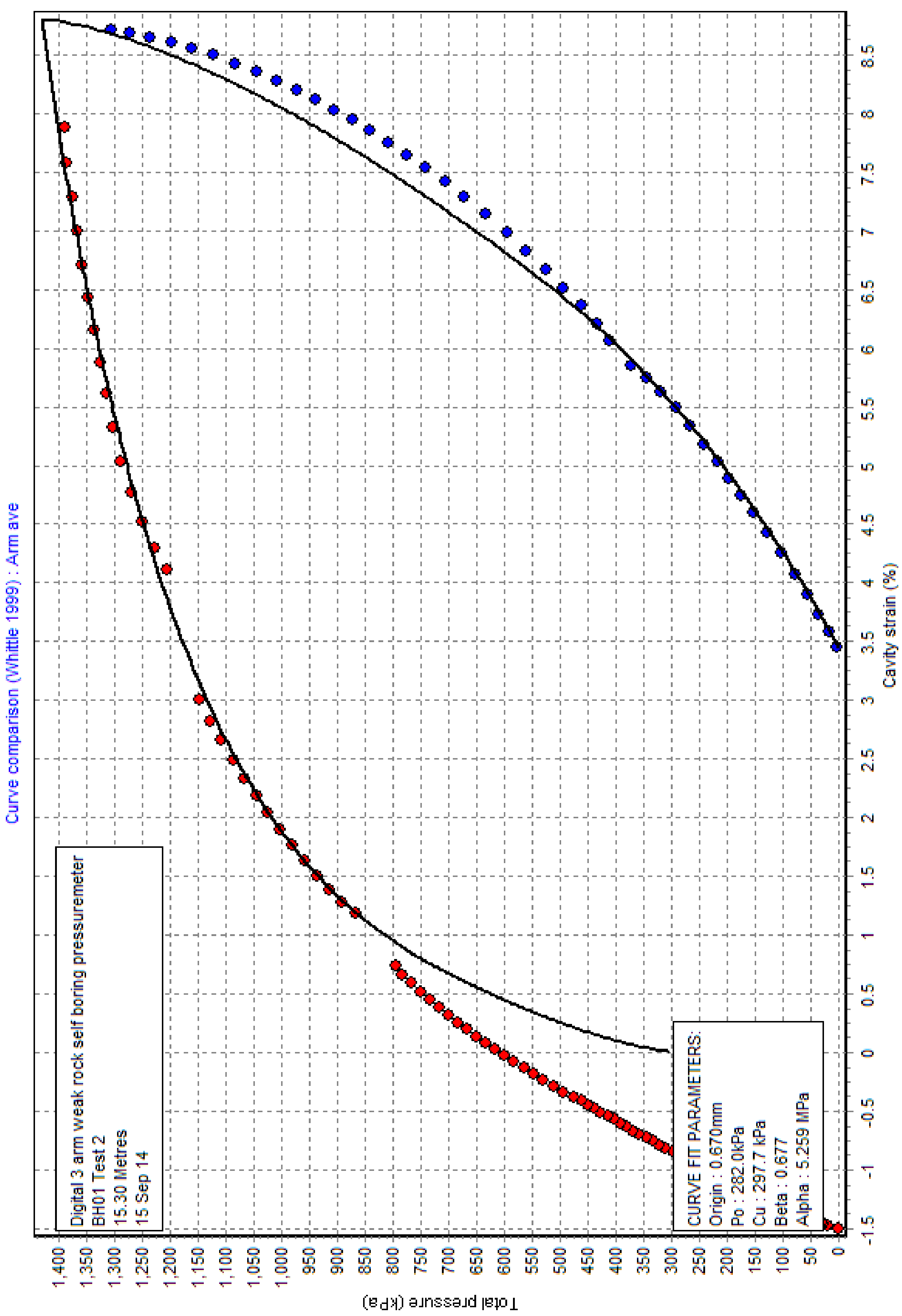

Shear modulus from unload/reload cycles Loop 3 : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 2
15.30 Metres
15 Sep 14
RESULTS:
Gur : 28.9MPa
Cycle mid-point:
Cavity strain : 6.284%
Total stress : 597kPa
Size of cycle :
Shear strain : 1.278%
Total stress : 372kPa
Radial Displacement (mm)
3.22
3.24
3.26
3.28
3.3
3.32
3.34
3.36
3.38
3.4
3.42
3.44
3.46
3.48
3.5
3.52
3.54
3.56
3.58
3.6
3.62
3.64
3.66
3.68
3.7
3.72
3.74
Total pressure (kPa)
800
780
760
740
720
700
680
660
640
620
600
580
560
540
520
500
480
460
440
420
400
380

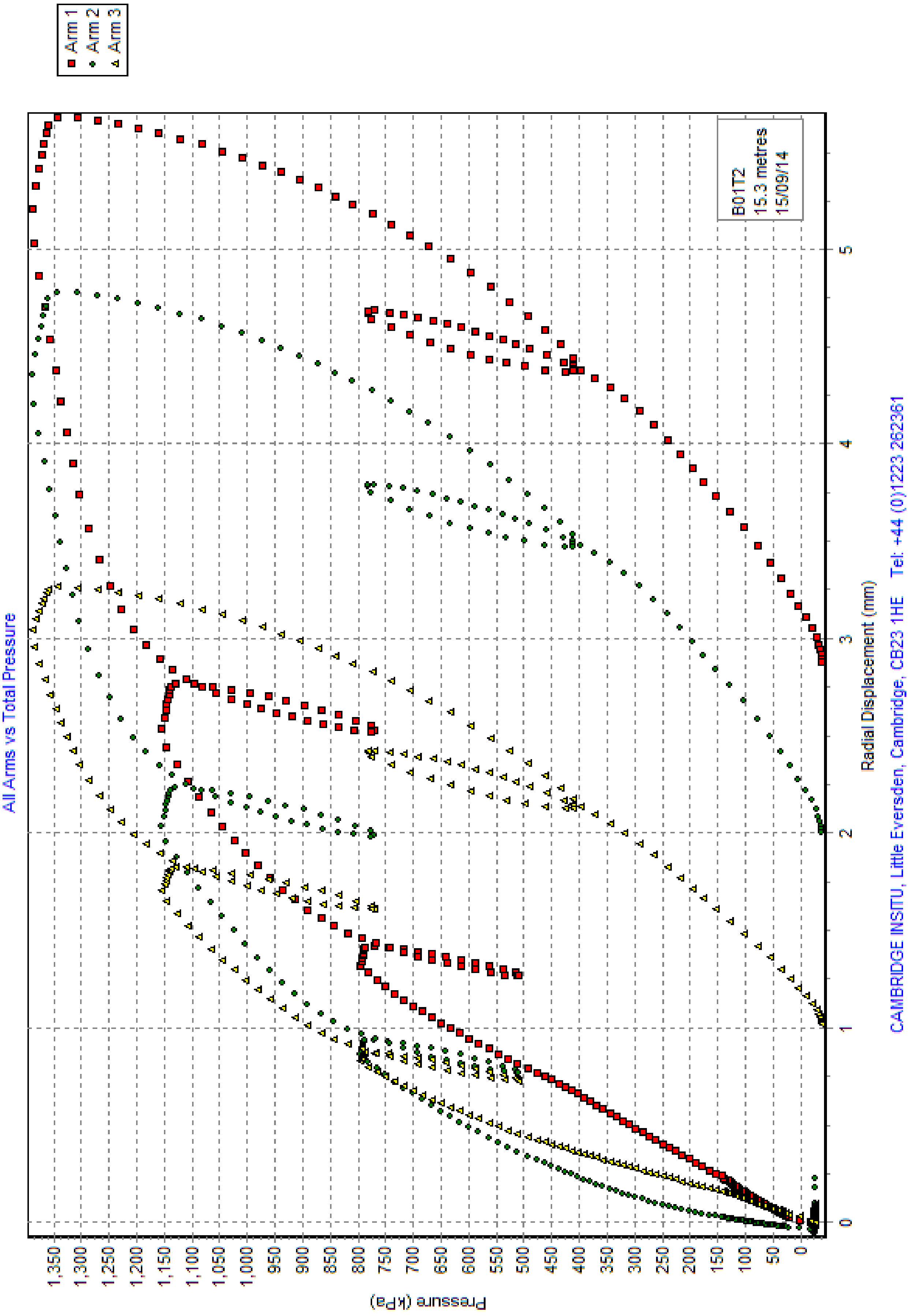

Bolton and Whittle (1999) Loop 1 : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 2
15.30 Metres
15 Sep 14
RESULTS:
Gradient (beta) : 0.740
Intercept (n) : 10.056MPa
Shear stress constant : 7.441MPa
Ln[Radial stress]
5.4
5.3
5.2
5.1
5
4.9
4.8
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
Ln[shear strain]
-8
-7
-6
Source data - Loop 1
Total pressure (kPa)
750
700
650
600
550
500
Radial Displacement (mm)
0.95
1
1.05


Bolton and Whittle (1999) Loop 2 : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 2
15.30 Metres
15 Sep 14
RESULTS:
Gradient (beta) : 0.713
Intercept (n) : 8.872MPa
Shear stress constant : 6.322MPa
Source data - Loop 2
Total pressure (kPa)
1,100
1,050
1,000
950
900
850
800
Radial Displacement (mm)
2.05
2.1
2.15
2.2
2.25
Ln[Radial stress]
5.6
5.4
5.2
5
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
Ln[shear strain]
-5
-6
-7
-8
-9
-10


Bolton and Whittle (1999) Loop 3 : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 2
15.30 Metres
15 Sep 14
RESULTS:
Gradient (beta) : 0.677
Intercept (n) : 7.582MPa
Shear stress constant : 5.133MPa
Ln[Radial stress]
5.8
5.7
5.6
5.5
5.4
5.3
5.2
5.1
5
4.9
4.8
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
Ln[shear strain]
-5
-6
-7
-8
-9
Source data - Loop 3
Total pressure (kPa)
800
700
600
500
Radial Displacement (mm)
3.4
3.5
3.6


Variation of stiffness with strain, undrained analysis : Arm ave
Cycle 1 - Measured
Cycle 1 - Calculated
Cycle 2 - Measured
Cycle 2 - Calculated
Cycle 3 - Measured
Cycle 3 - Calculated
POWER LAW PARAMETERS:
Cycle No. | Constant (MPa) | Gradient
1 | 7.441 | 0.740
2 | 6.322 | 0.713
3 | 5.133 | 0.677
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 2
15.30 Metres
15 Sep 14
Shear modulus (MPa)
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
0.0001
0.001
0.01
Log plane shear strain


Curve comparison (Whittle 1999) : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 2
15.30 Metres
15 Sep 14
CURVE FIT PARAMETERS:
Origin : 0.670mm
Po : 282.0kPa
Cu : 297.7 kPa
Beta : 0.677
Alpha : 5.259 MPa
Cavity strain (%)
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
Total pressure (kPa)
1,400
1,350
1,300
1,250
1,200
1,150
1,100
1,050
1,000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0


All Arms vs Total Pressure
■ Arm 1
● Arm 2
▲ Arm 3
B01T2
15.3 metres
15/09/14
Radial Displacement (mm)
0
1
2
3
4
5
Pressure (kPa)
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1,000
1,050
1,100
1,150
1,200
1,250
1,300
1,350
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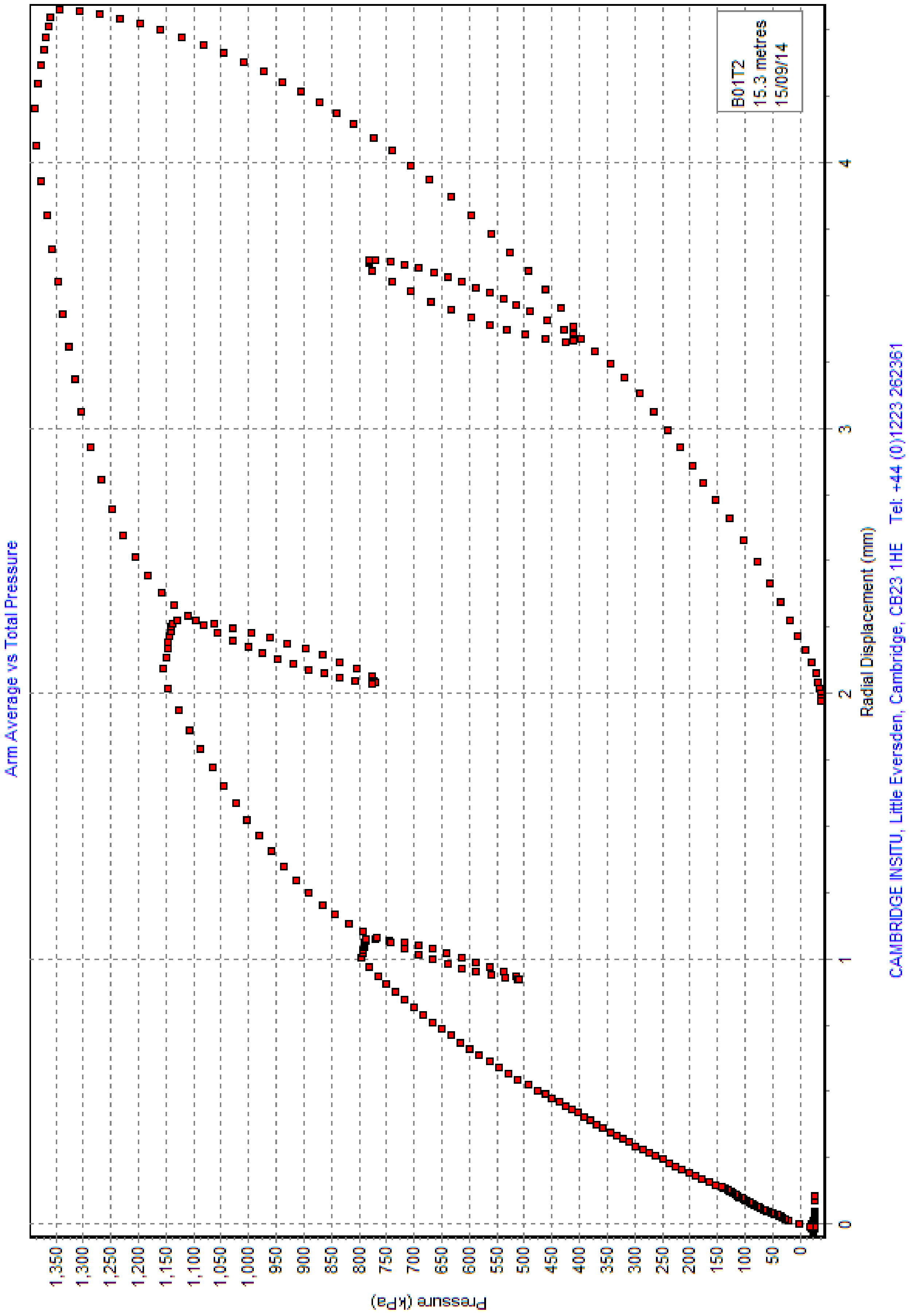
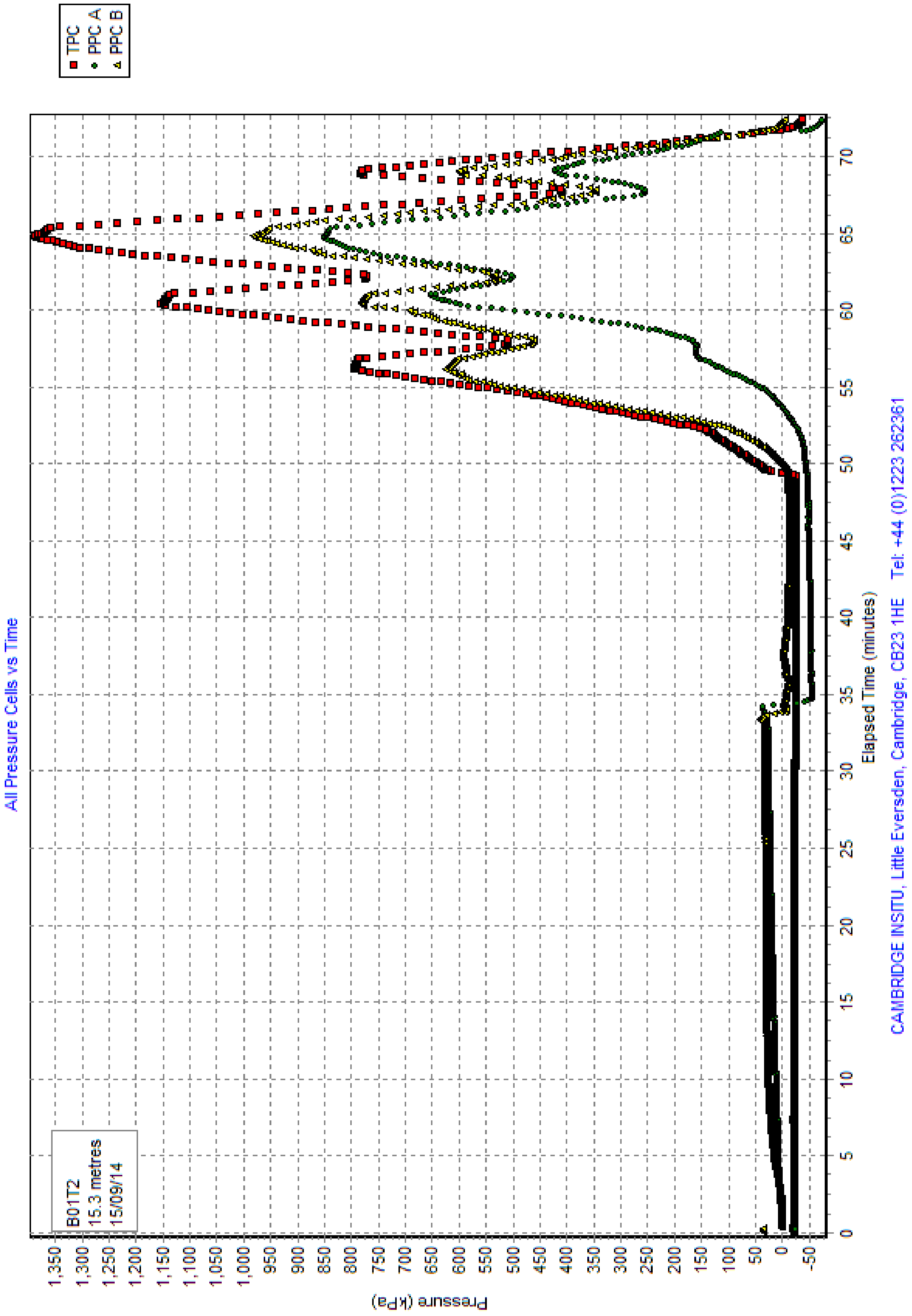
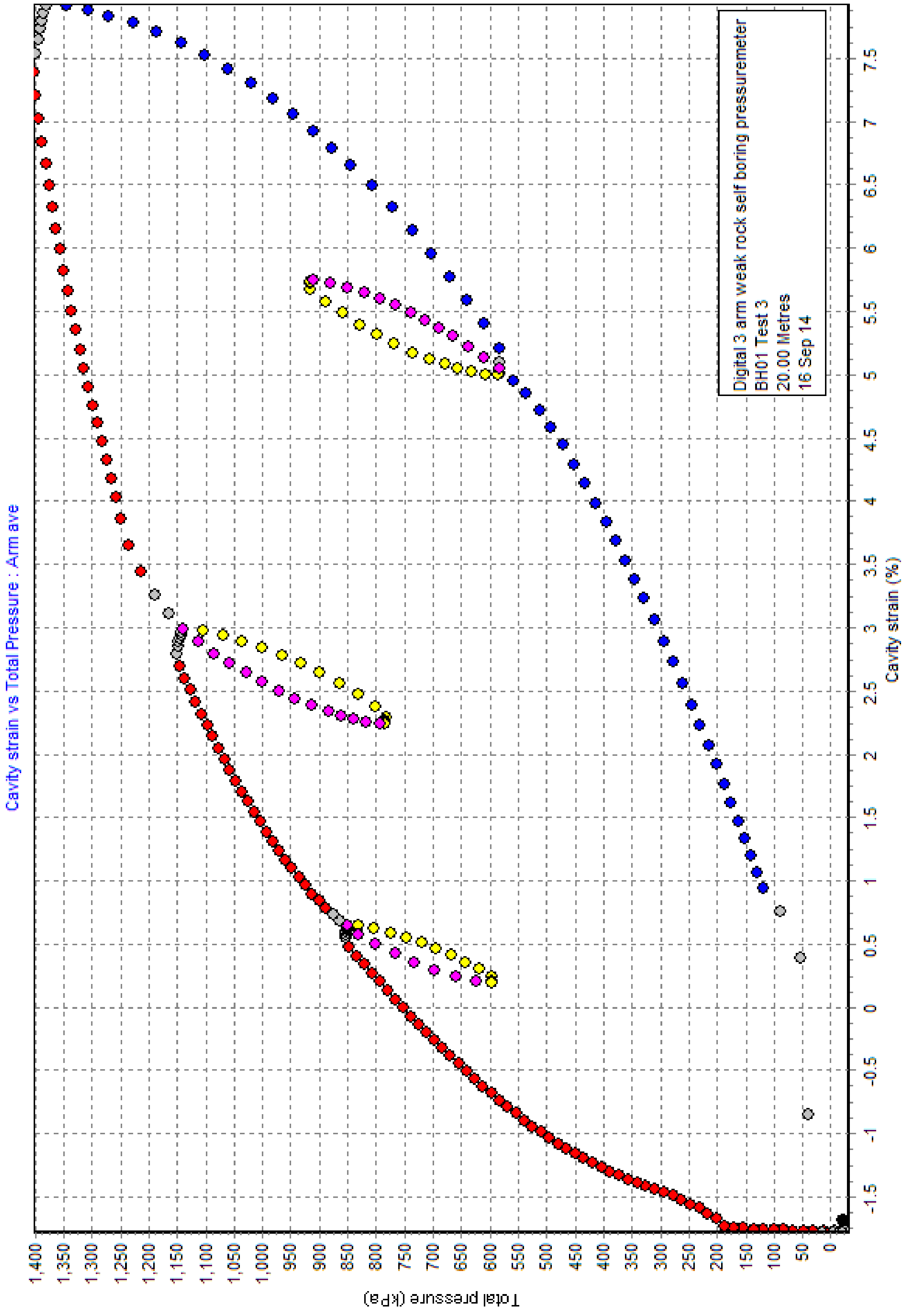
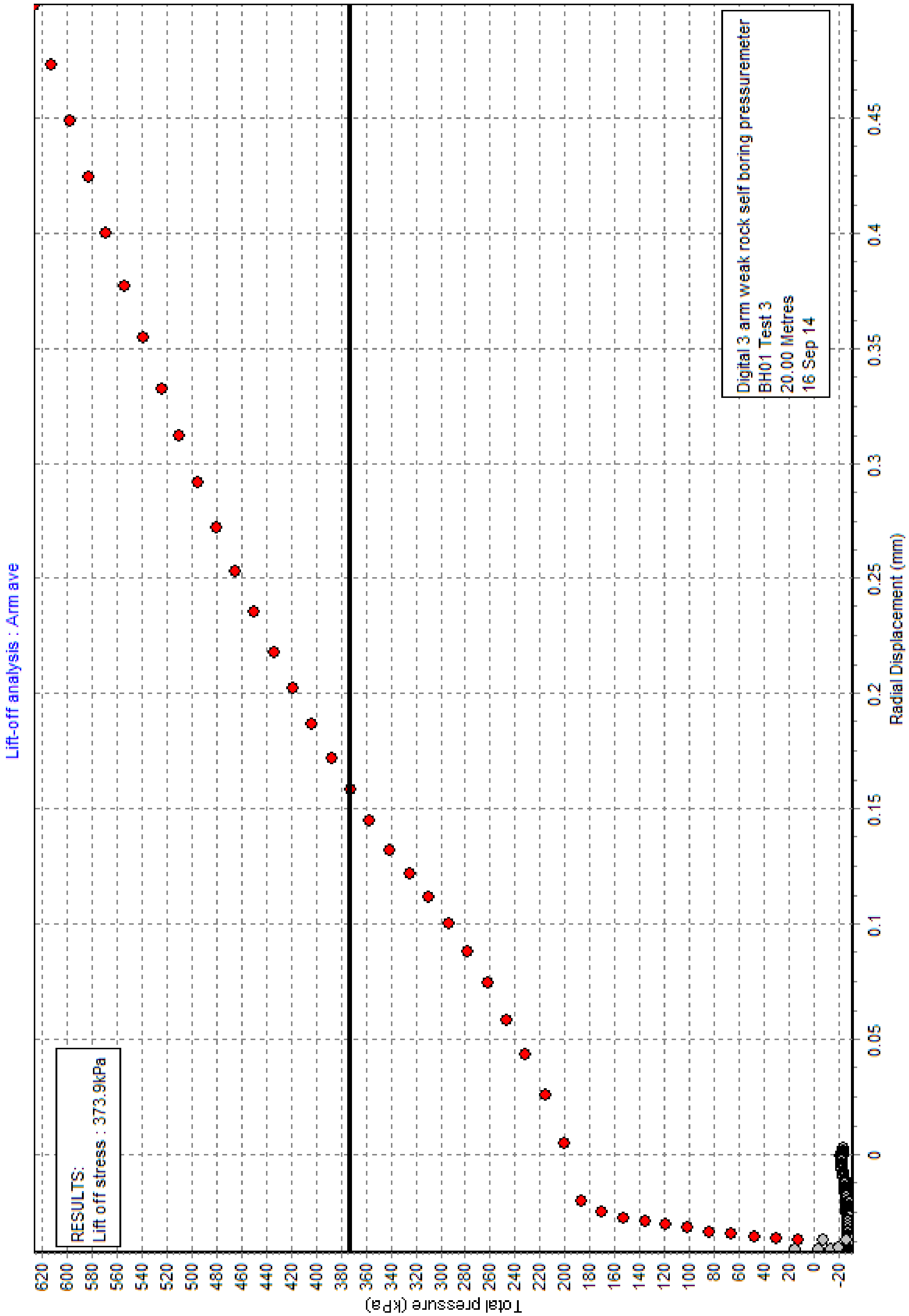
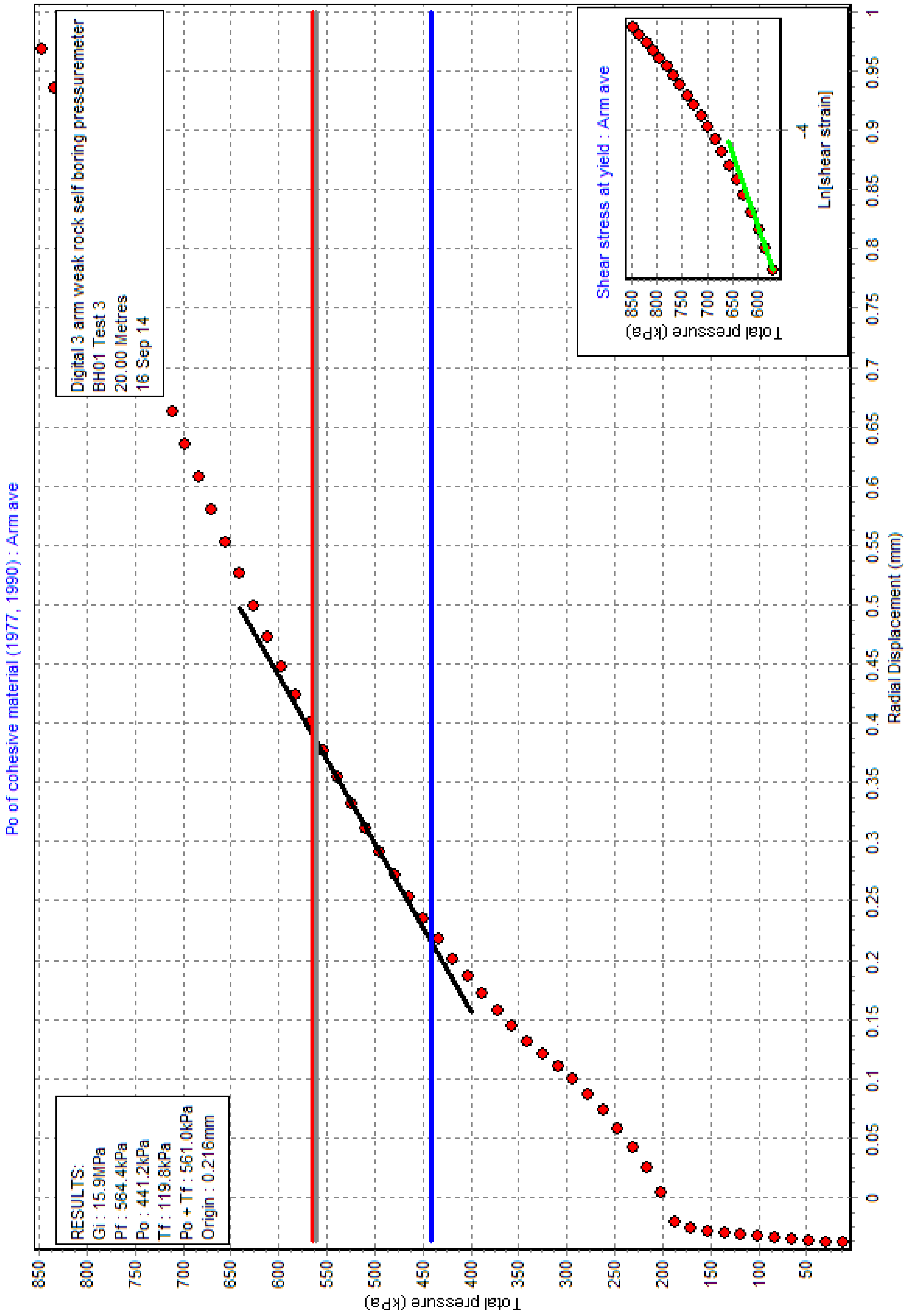

Arm Average vs Total Pressure
Pressure (kPa)
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1,000
1,050
1,100
1,150
1,200
1,250
1,300
1,350
Radial Displacement (mm)
0
1
2
3
4
B01T2
15.3 metres
15/09/14
CAMBRIDGE INSITU, Little Eversden, Cambridge, CB23 1HE Tel: +44 (0)1223 262361

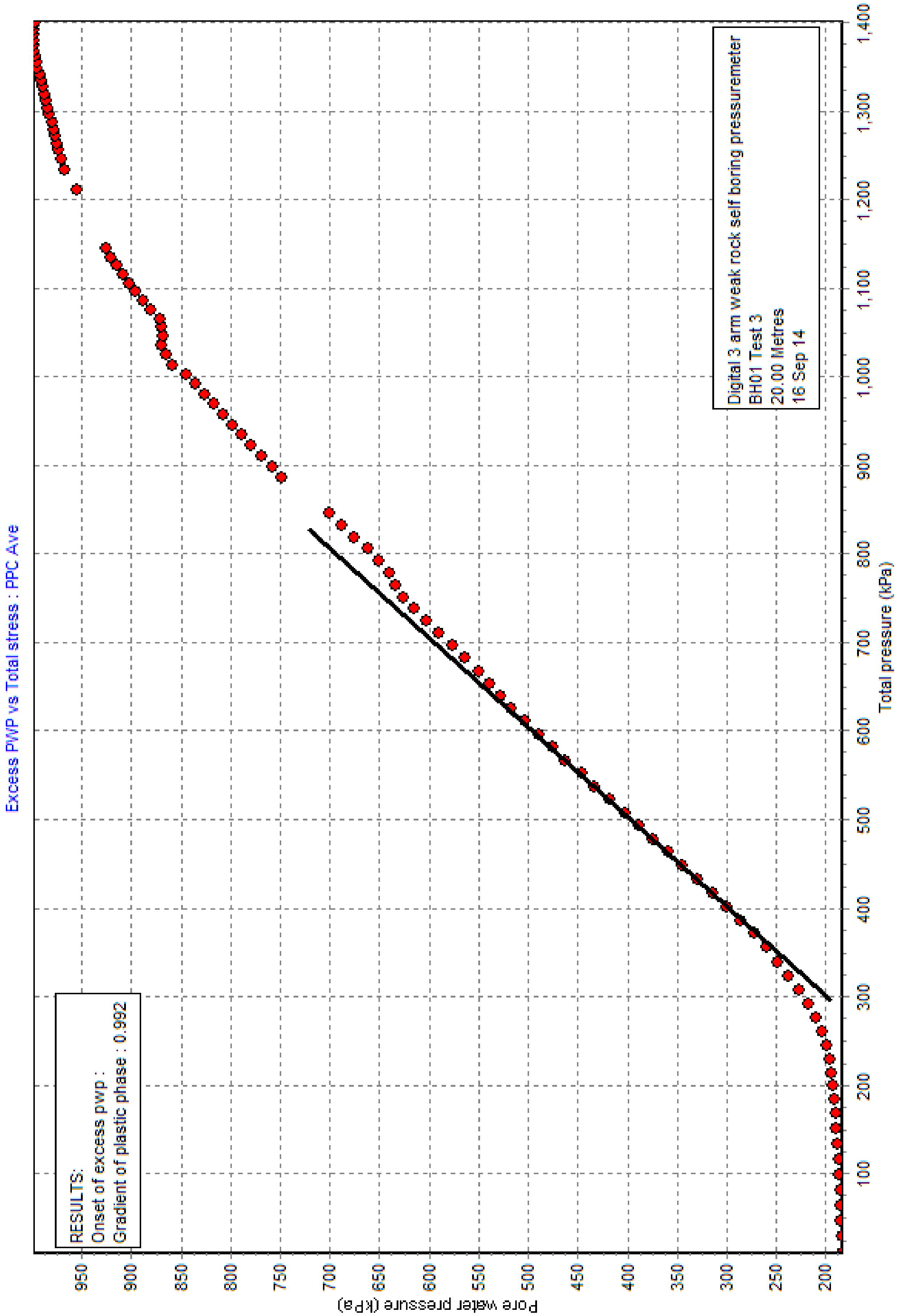

All Pressure Cells vs Time
■ TPC
● PPC A
△ PPC B
B01T2
15.3 metres
15/09/14
Pressure (kPa)
1,350
1,300
1,250
1,200
1,150
1,100
1,050
1,000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
-50
Elapsed Time (minutes)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
CAMBRIDGE INSITU, Little Eversden, Cambridge, CB23 1HE Tel: +44 (0)1223 262361

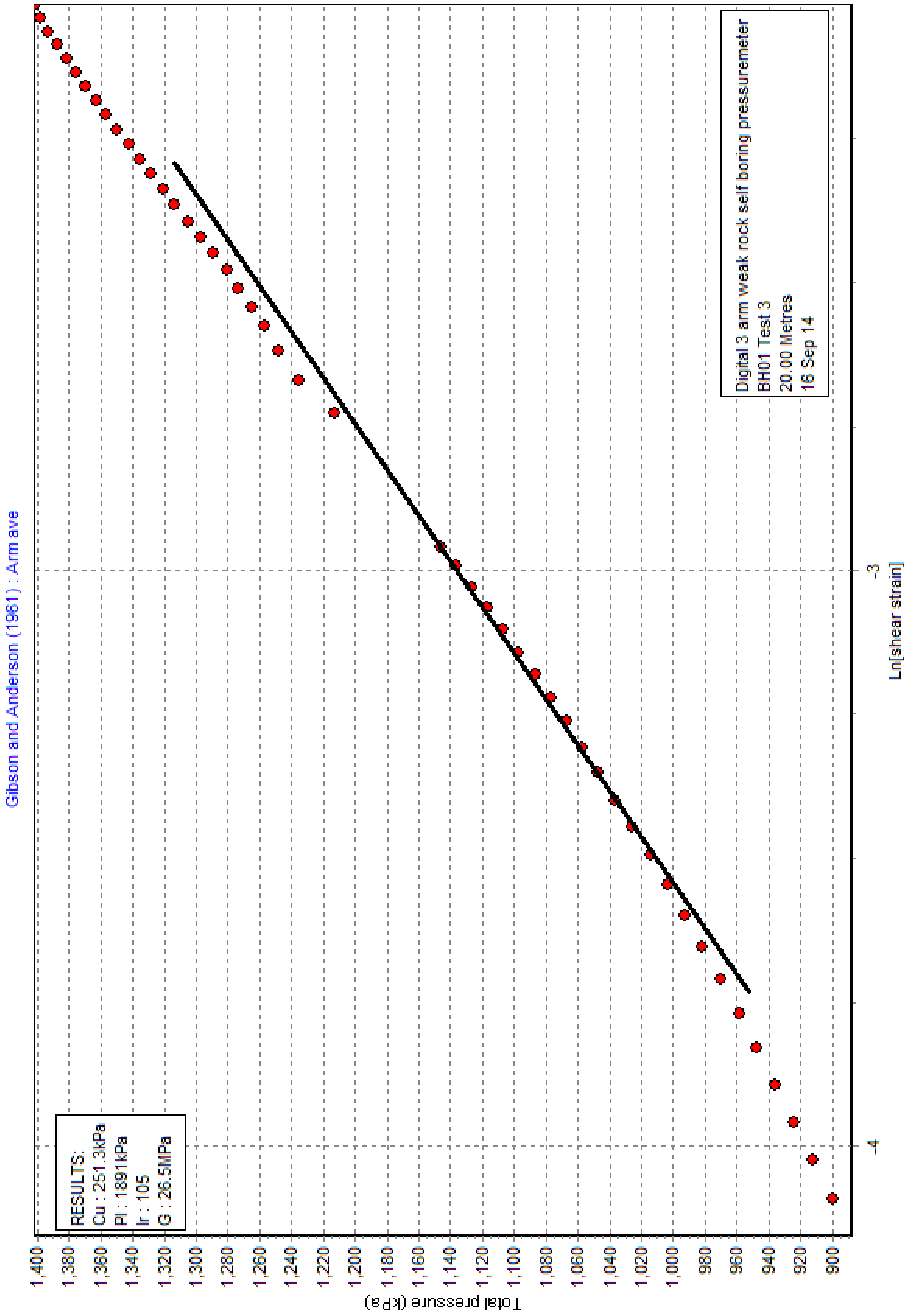
```
BH01 Test 3 - SUMMARY OF RESULTS
[File made with WinSitu  Version 3.6.1.1]

[DETAILS OF TEST]
Project        :
Site           :   1 Bedford Avenue
Borehole       :   BH01
Test name      :   BH01 Test 3
Test date      :   16 Sep 14
Test depth     :   20.00 Metres
Water table    :   Nothing entered
Ambient PWP    :   0.0 kPa
Material       :   London Clay
Probe          :   Digital 3 arm weak rock self boring pressuremeter
Diameter       :   88.1 mm
Data analysed using average arm displacement curve
A non-linear analysis of the rebound cycles has been carried out
The file includes results from a curve fitting analysis

Analysed by SDB on 14 Oct 14

Remarks:  Lost flush to hole for most of drilling. Bottom partially
blocked off.

[RESULTS FOR CAVITY REFERENCE PRESSURE]
Strain Origin (mm)                   :   "Arm ave=0.750"
Po from Marsland & Randolph (kPa)    :   "Arm ave=441.2"
Po from Lift off (kPa)               :   "Arm ave=373.9"
Best estimate of Po (kPa)            :   "Arm ave=469.0"

[UNDRAINED STRENGTH PARAMETERS]
Gibson & Anderson 1961 - Cu (kPa)    :   "Arm ave=251.3"
Limit pressure (kPa)                 :   "Arm ave=1891"
Jefferies 1988 - Cu (kPa)            :   "Arm ave=251.9"
Undrained yield stress (kPa)         :   "Arm ave=564.4"

[LINEAR INTERPRETATION OF SHEAR MODULUS G]
Initial slope shear modulus (MPa) :"Arm ave=15.9"
Axis       Loop   Value    Mean Strain  Mean Pc  dE      dPc
           No     (MPa)    (%)          (kPa)    (%)     (kPa)
Arm ave    1      28.2     0.429        723      0.892   252
Arm ave    2      24.5     2.626        961      1.441   355
Arm ave    3      24.0     5.367        751      1.376   333

[UNDRAINED NON LINEAR INTERPRETATION OF SECANT SHEAR MODULUS]
Axis       Loop   Intercept  Alpha      Gradient
           No     (MPa)      (MPa)
Arm ave    1      5.535      3.595      0.649
Arm ave    2      5.563      3.585      0.644
Arm ave    3      5.329      3.394      0.637


[PARAMETERS USED FOR UNDRAINED CURVE MODELLING]
{Axis is  Arm ave}
Strain Origin (mm)                   :   0.75
Po (kPa)                             :   469
Cu (kPa)                             :   251.3
Limit pressure (kPa)                 :   1891
Non-linear exponent                  :   0.637
Calculated alpha (MPa)               :   3.395
G at yield (MPa)                     :   15.0
```

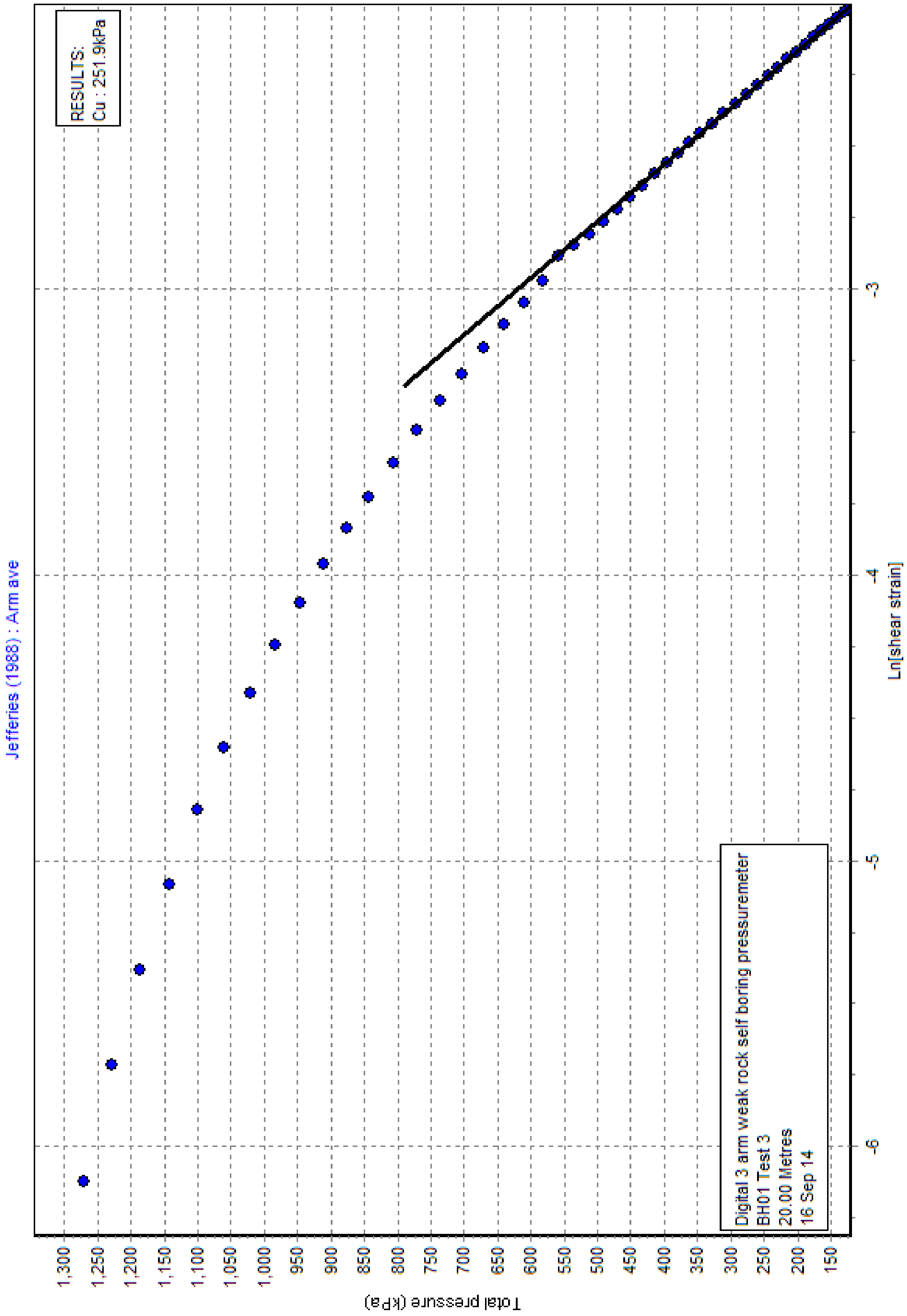

Cavity strain vs Total Pressure : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
Cavity strain (%)
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
Total pressure (kPa)
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1,000
1,050
1,100
1,150
1,200
1,250
1,300
1,350
1,400

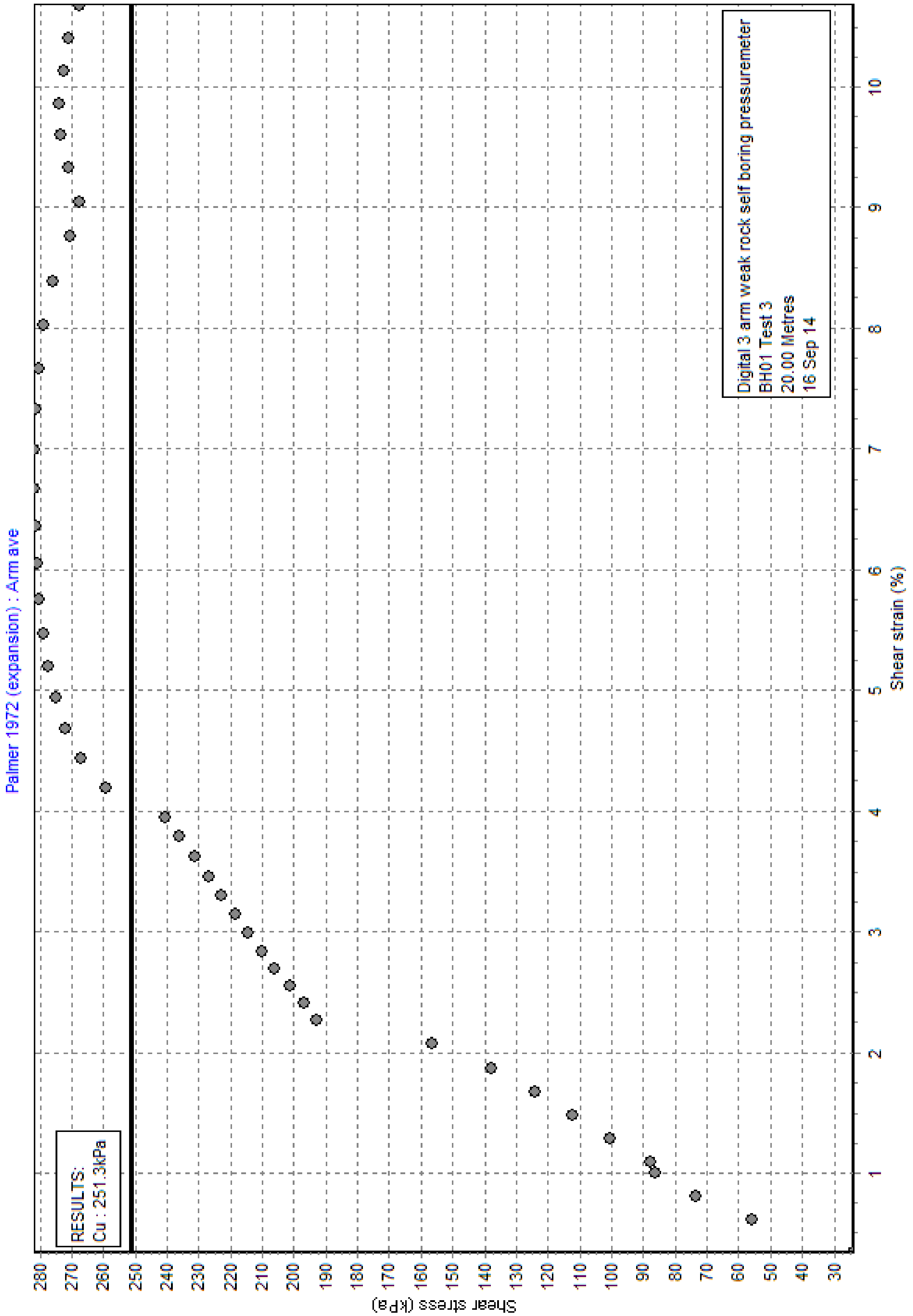

Lift-off analysis : Arm ave
RESULTS:
Lift off stress : 373.9kPa
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
Total pressure (kPa)
620
600
580
560
540
520
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
Radial Displacement (mm)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45

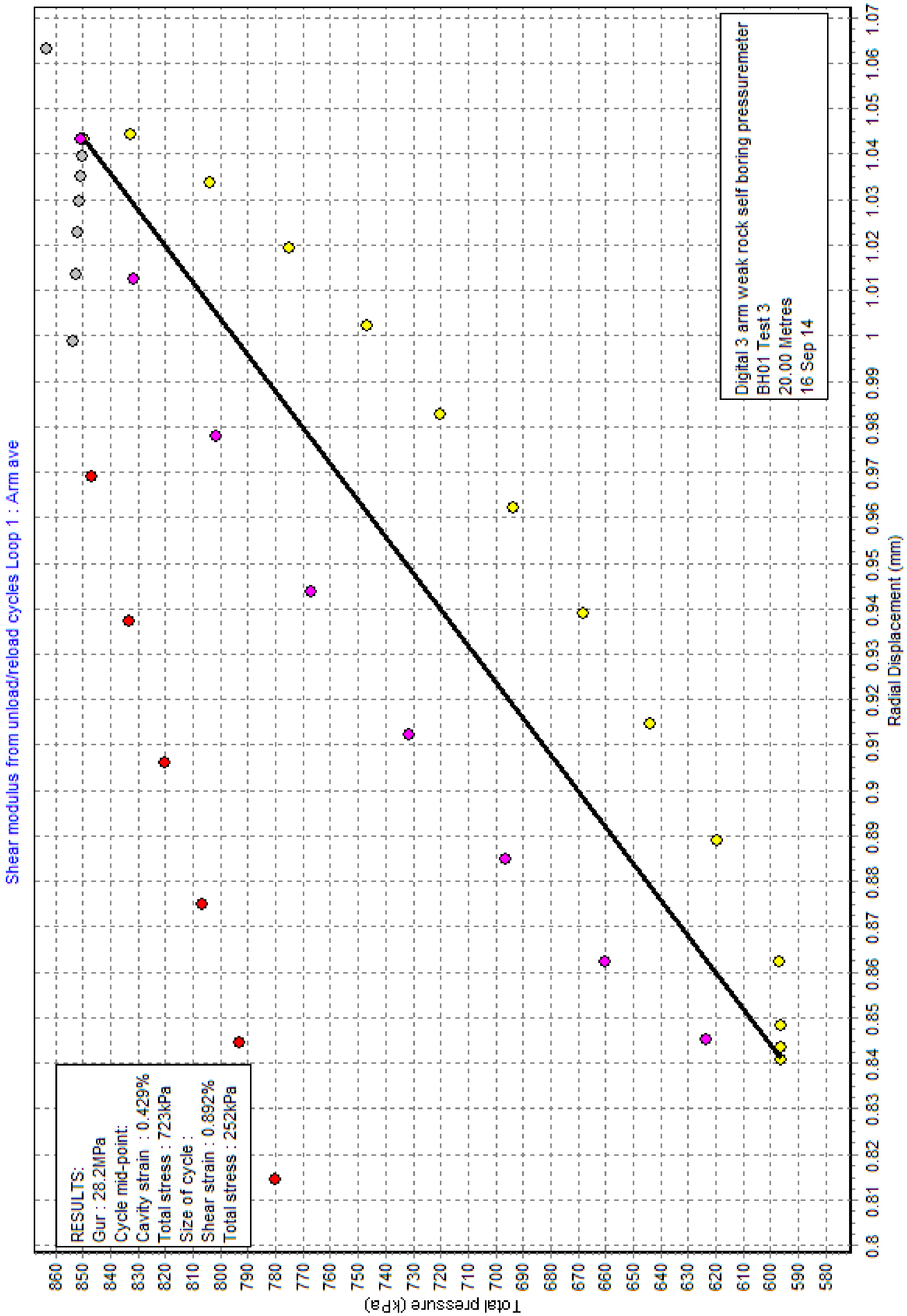

Po of cohesive material (1977, 1990) : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
RESULTS:
Gi : 15.9MPa
Pf : 564.4kPa
Po : 441.2kPa
Tf : 119.8kPa
Po + Tf : 561.0kPa
Origin : 0.216mm
Shear stress at yield : Arm ave
Total pressure (kPa)
850
800
750
700
650
600
-4
Ln[shear strain]
Total pressure (kPa)
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
Radial Displacement (mm)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1


Excess PWP vs Total stress : PPC Ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
RESULTS:
Onset of excess pwp :
Gradient of plastic phase : 0.992
Pore water pressure (kPa)
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
Total pressure (kPa)
100
200
300
400
500
600
700
800
900
1,000
1,100
1,200
1,300
1,400


Gibson and Anderson (1961) : Arm ave
RESULTS:
Cu : 251.3kPa
Pl : 1891kPa
Ir : 105
G : 26.5MPa
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
Total pressure (kPa)
1,400
1,380
1,360
1,340
1,320
1,300
1,280
1,260
1,240
1,220
1,200
1,180
1,160
1,140
1,120
1,100
1,080
1,060
1,040
1,020
1,000
980
960
940
920
900
Ln[shear strain]
-4
-3

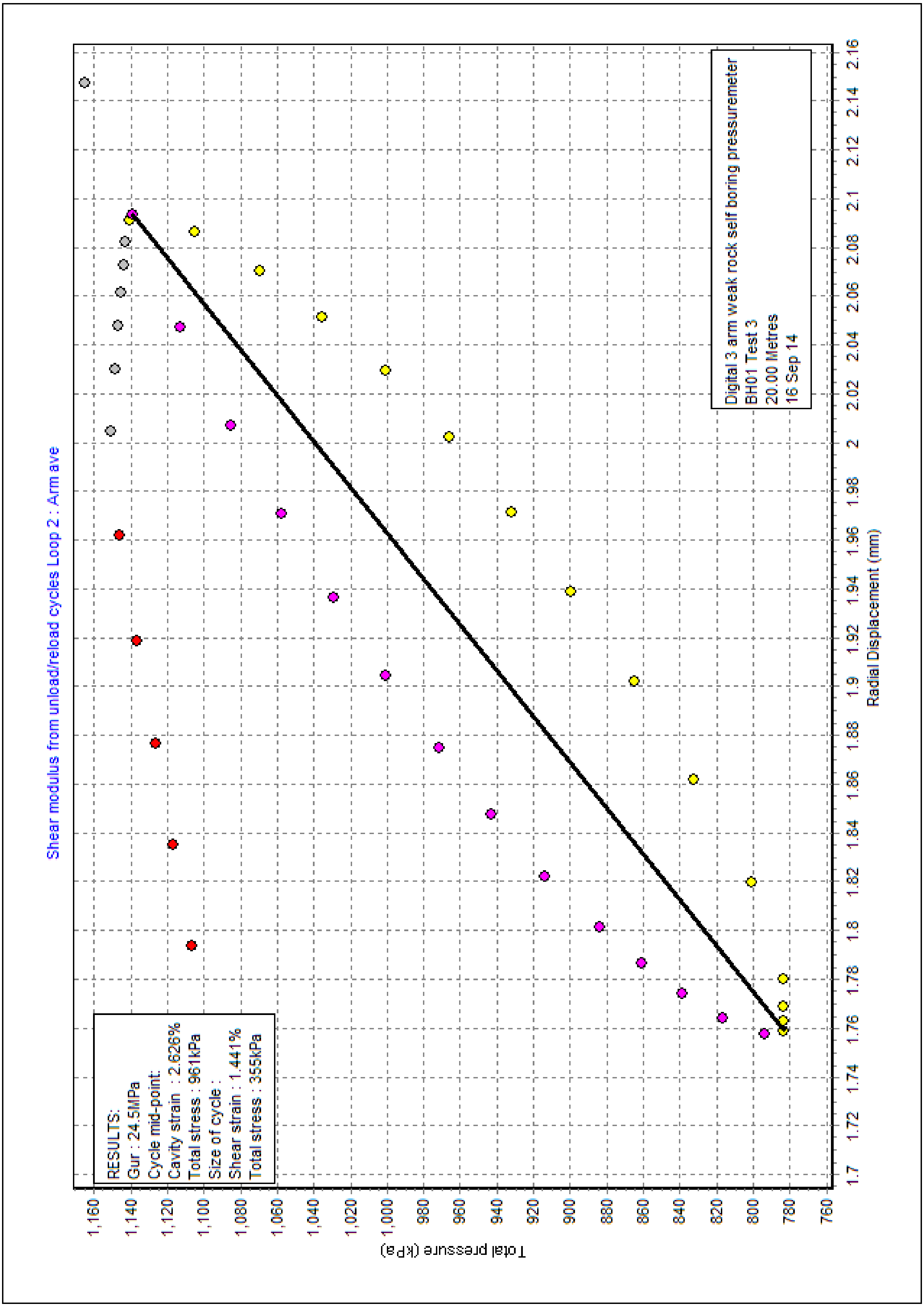

RESULTS:
Cu : 251.9kPa
Jefferies (1988) : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
Ln[shear strain]
-3
-4
-5
-6
Total pressure (kPa)
1,300
1,250
1,200
1,150
1,100
1,050
1,000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150


Palmer 1972 (expansion) : Arm ave
RESULTS:
Cu : 251.3kPa
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
Shear stress (kPa)
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
Shear strain (%)
1
2
3
4
5
6
7
8
9
10



Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14

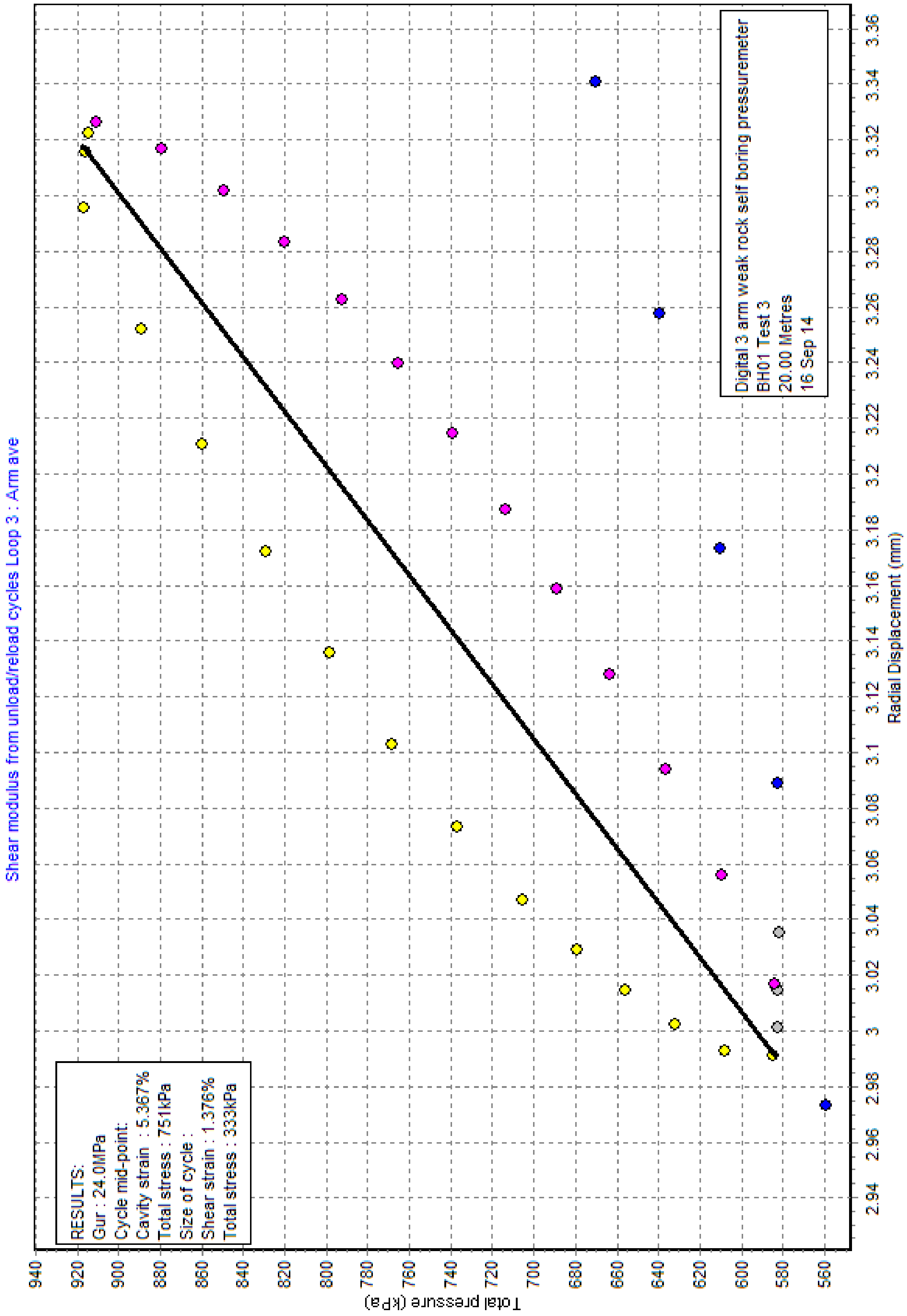
RESULTS:
Gur : 28.2MPa
Cycle mid-point:
Cavity strain : 0.429%
Total stress : 723kPa
Size of cycle :
Shear strain : 0.892%
Total stress : 252kPa

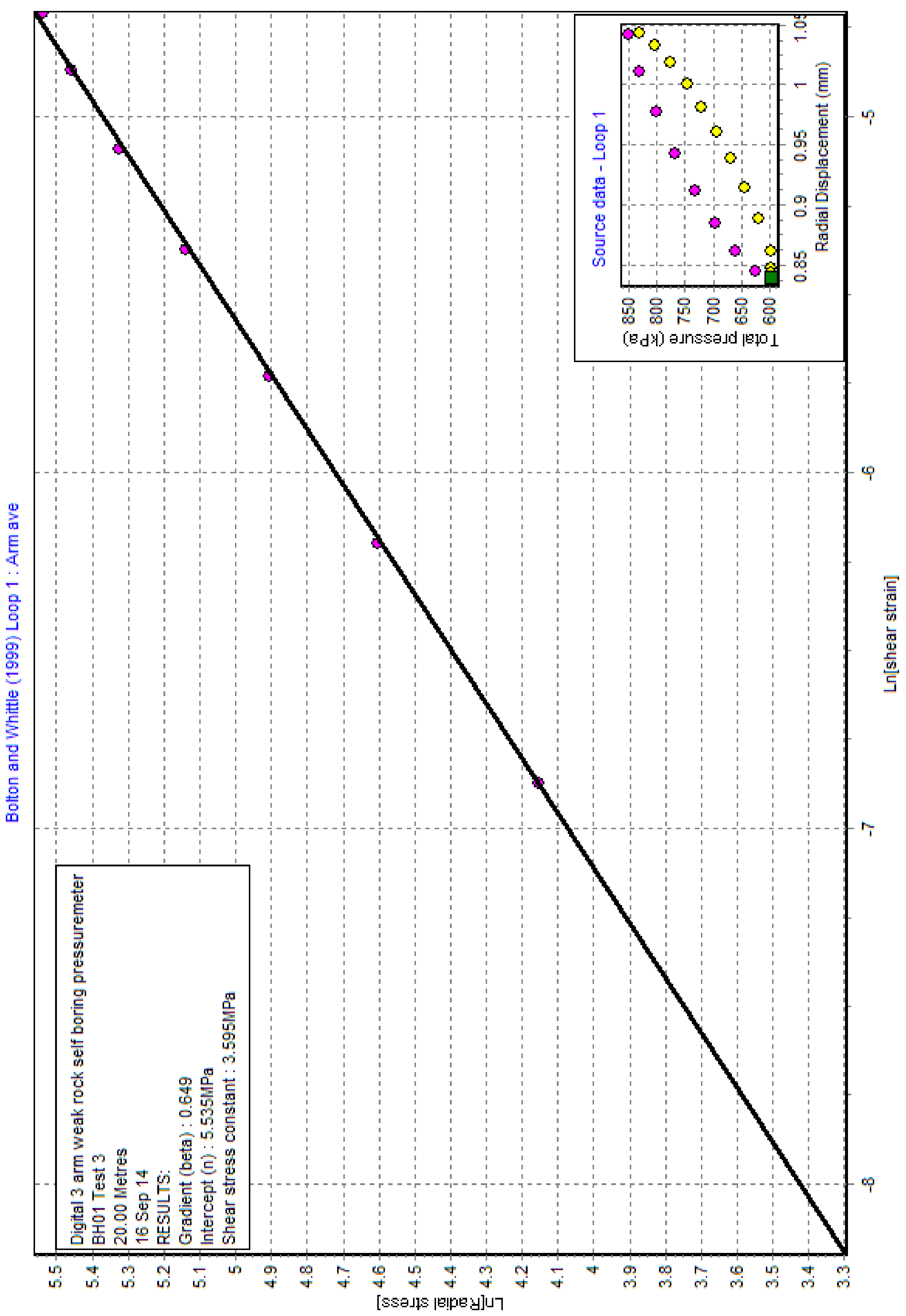


Shear modulus from unload/reload cycles Loop 2 : Arm ave

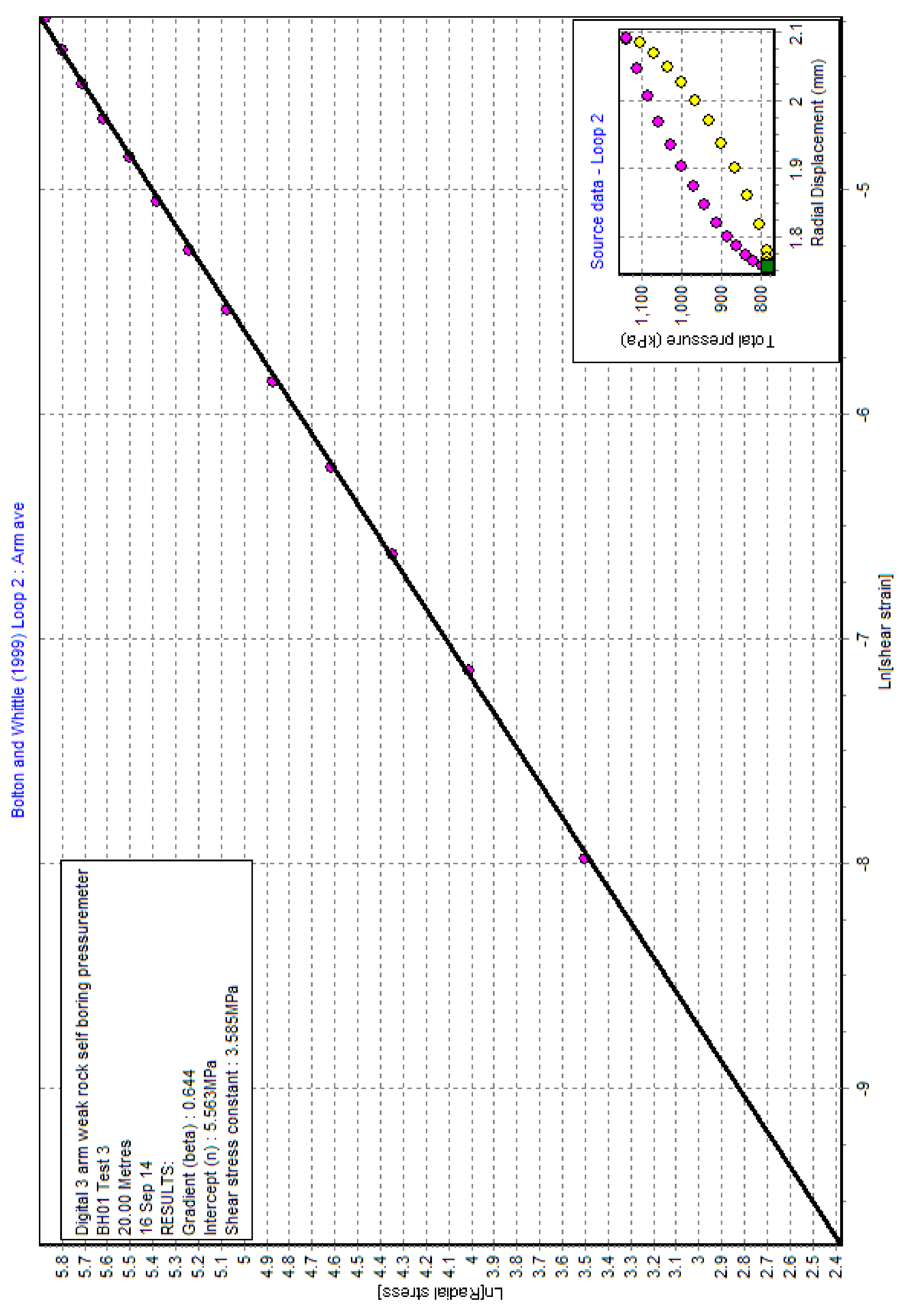
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14

RESULTS:
Gur : 24.5MPa
Cycle mid-point:
Cavity strain : 2.626%
Total stress : 961kPa
Size of cycle :
Shear strain : 1.441%
Total stress : 355kPa

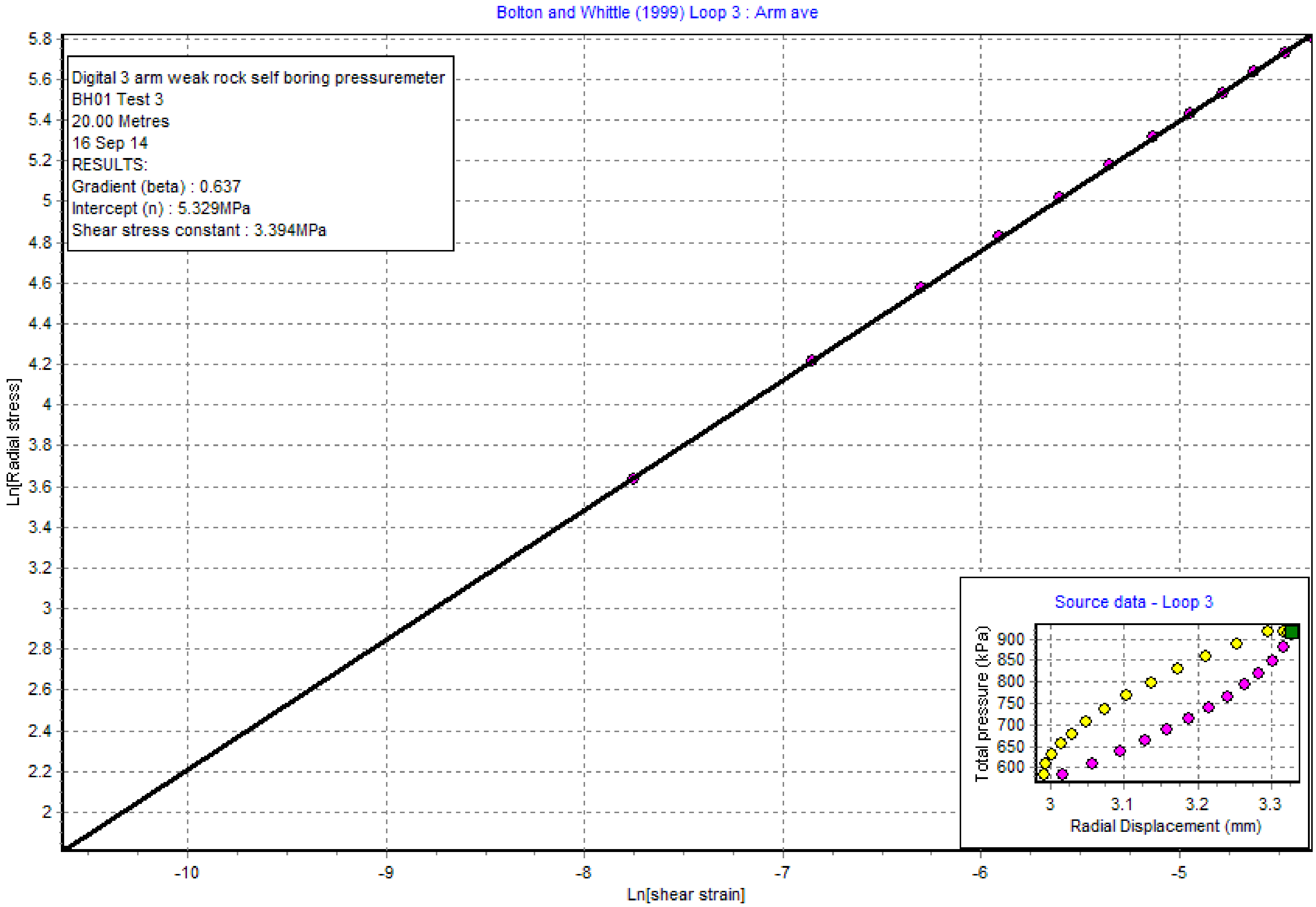

Shear modulus from unload/reload cycles Loop 3 : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
RESULTS:
Gur : 24.0MPa
Cycle mid-point:
Cavity strain : 5.367%
Total stress : 751kPa
Size of cycle :
Shear strain : 1.376%
Total stress : 333kPa
Radial Displacement (mm)
2.94
2.96
2.98
3
3.02
3.04
3.06
3.08
3.1
3.12
3.14
3.16
3.18
3.2
3.22
3.24
3.26
3.28
3.3
3.32
3.34
3.36
Total pressure (kPa)
560
580
600
620
640
660
680
700
720
740
760
780
800
820
840
860
880
900
920
940

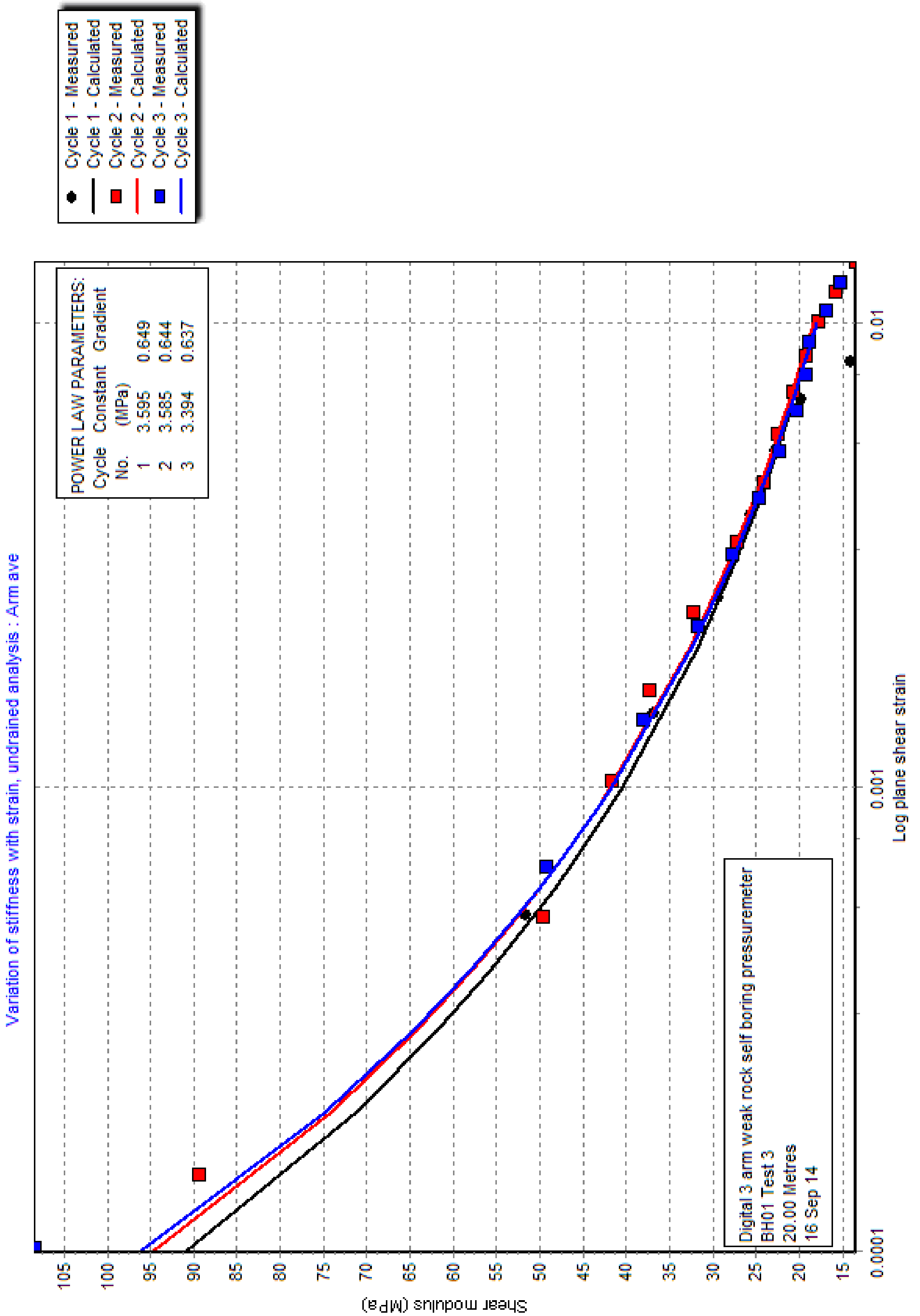


Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
RESULTS:
Gradient (beta) : 0.649
Intercept (n) : 5.535MPa
Shear stress constant : 3.595MPa



Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
RESULTS:
Gradient (beta) : 0.644
Intercept (n) : 5.563MPa
Shear stress constant : 3.585MPa

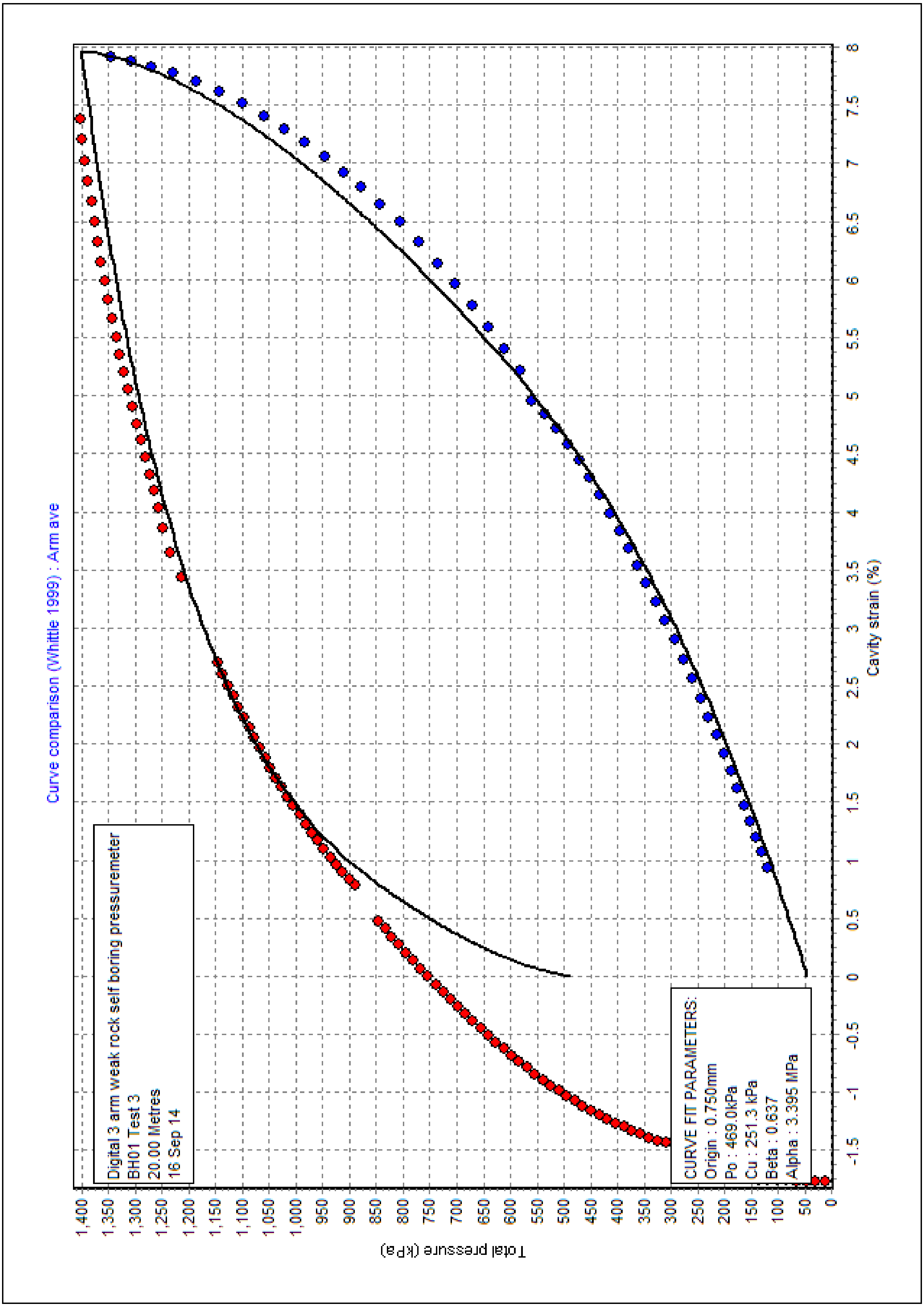

Bolton and Whittle (1999) Loop 3 : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
RESULTS:
Gradient (beta) : 0.637
Intercept (n) : 5.329MPa
Shear stress constant : 3.394MPa
Ln[Radial stress]
5.8
5.6
5.4
5.2
5
4.8
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
-10
-9
-8
-7
-6
-5
Ln[shear strain]
Source data - Loop 3
Total pressure (kPa)
900
850
800
750
700
650
600
3
3.1
3.2
3.3
Radial Displacement (mm)

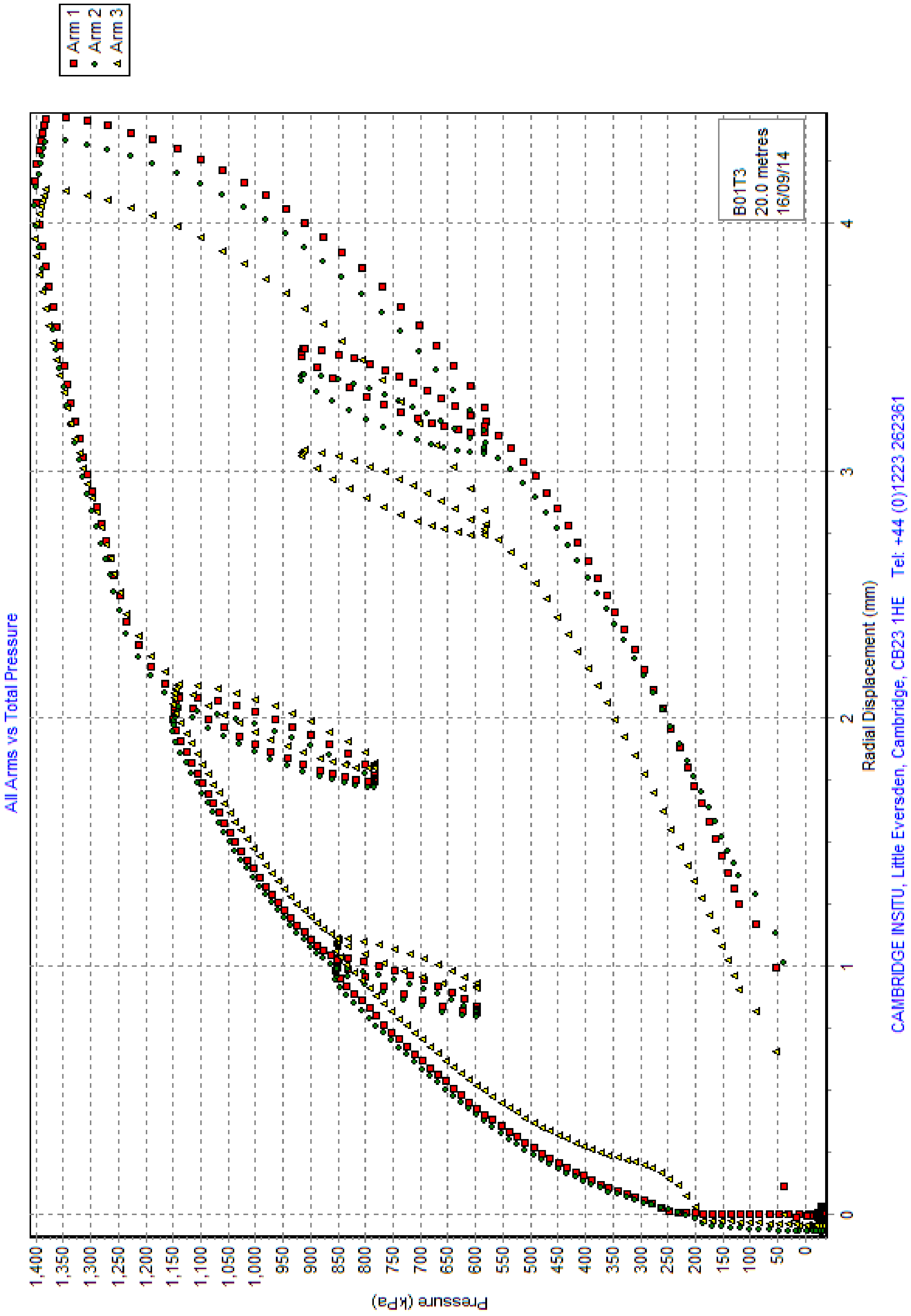


POWER LAW PARAMETERS:

Cycle No.	Constant (MPa)	Gradient
1	3.595	0.649
2	3.585	0.644
3	3.394	0.637

Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14


Curve comparison (Whittle 1999) : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
CURVE FIT PARAMETERS:
Origin : 0.750mm
Po : 469.0kPa
Cu : 251.3 kPa
Beta : 0.637
Alpha : 3.395 MPa
Cavity strain (%)
Total pressure (kPa)
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1,000
1,050
1,100
1,150
1,200
1,250
1,300
1,350
1,400


All Arms vs Total Pressure
Arm 1
Arm 2
Arm 3
B01T3
20.0 metres
16/09/14
Pressure (kPa)
1,400
1,350
1,300
1,250
1,200
1,150
1,100
1,050
1,000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Radial Displacement (mm)
0
1
2
3
4
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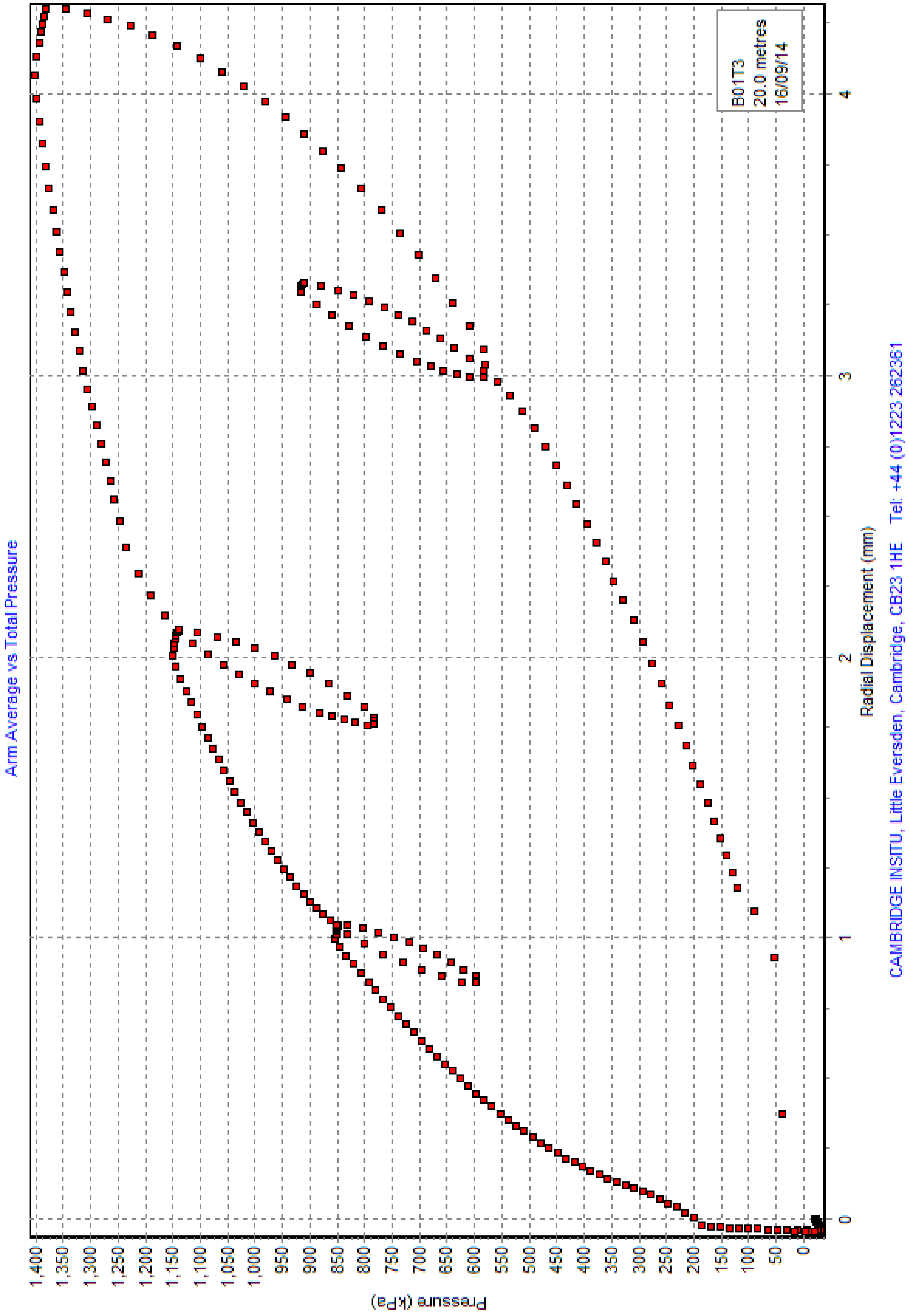
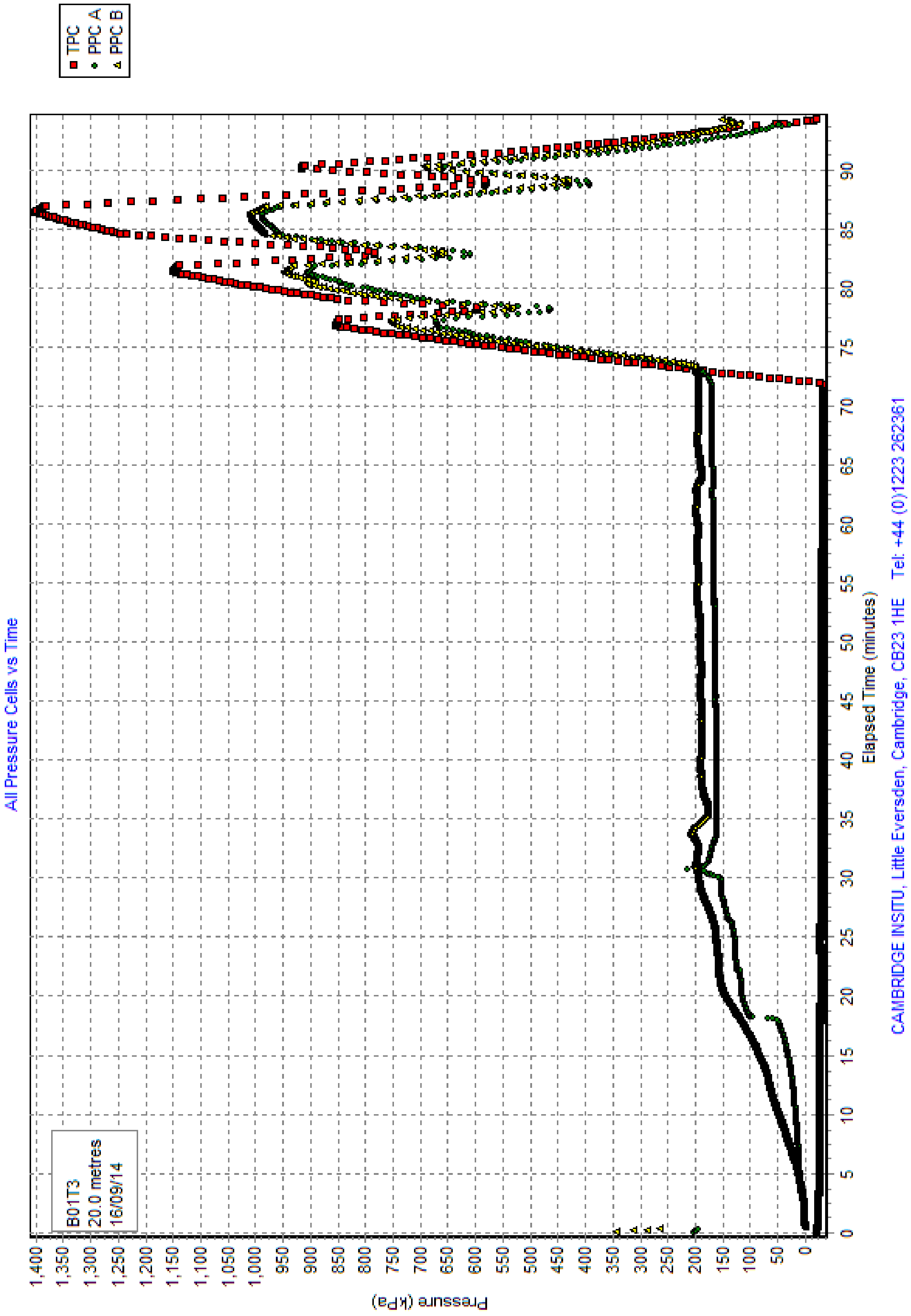
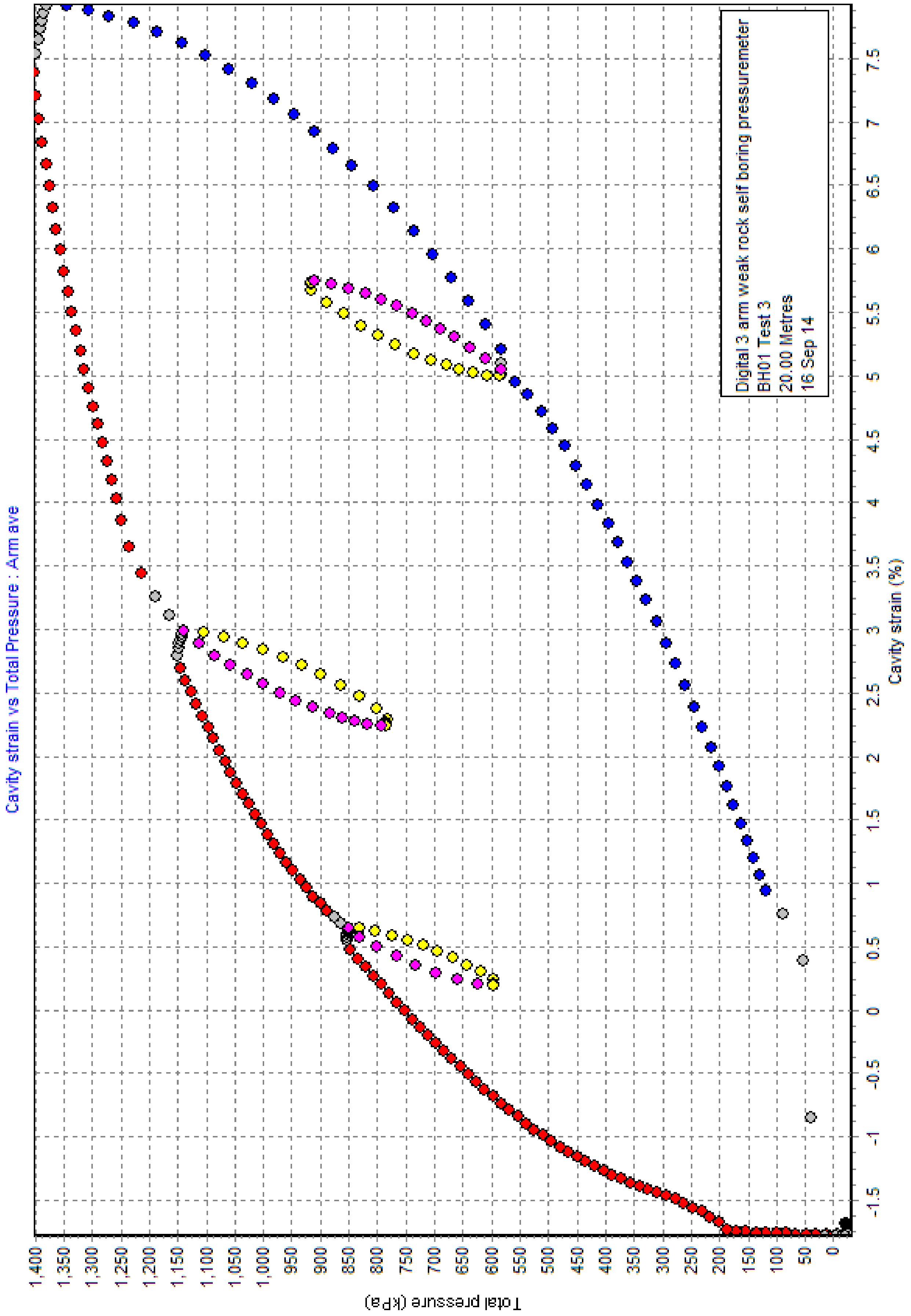
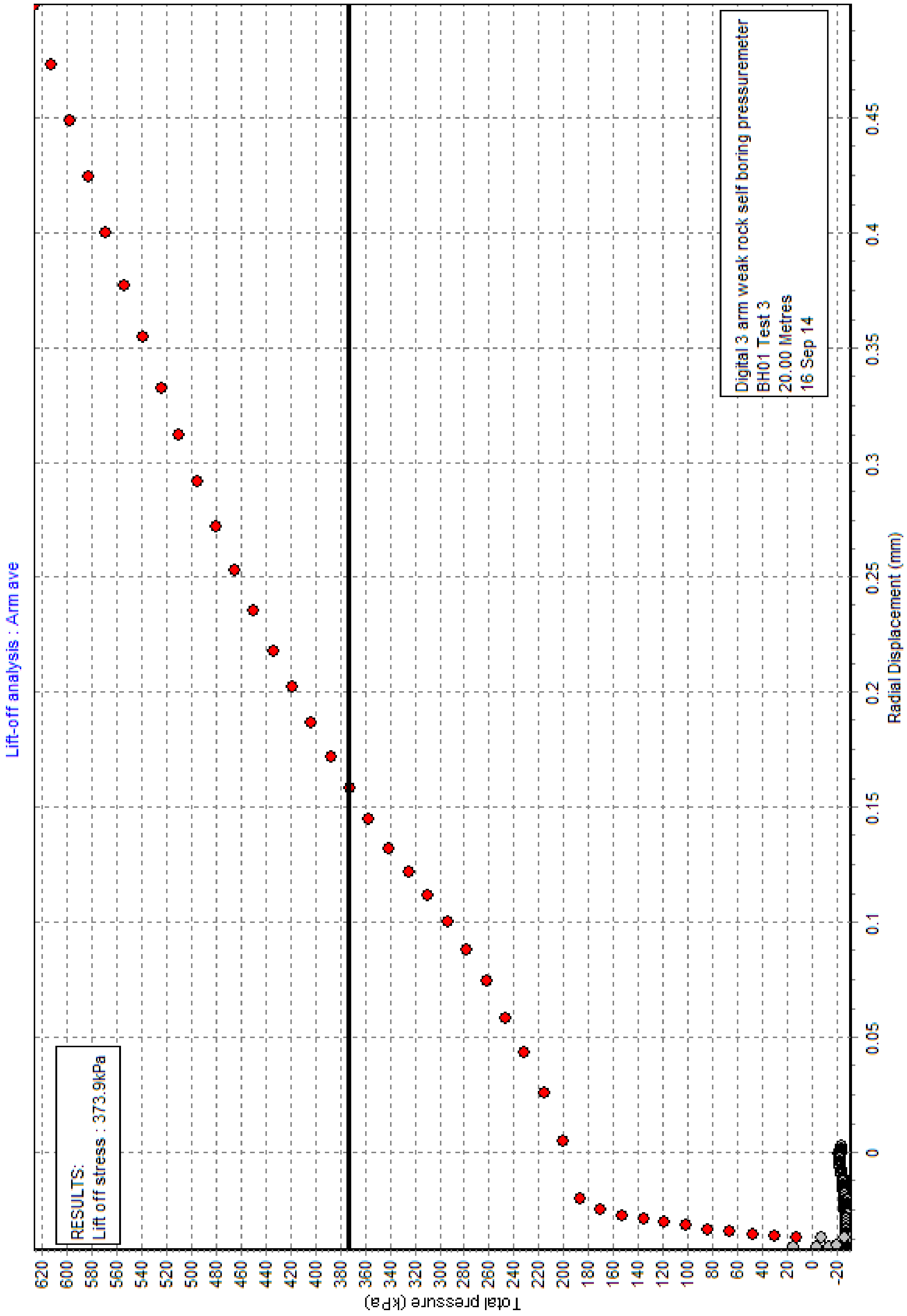
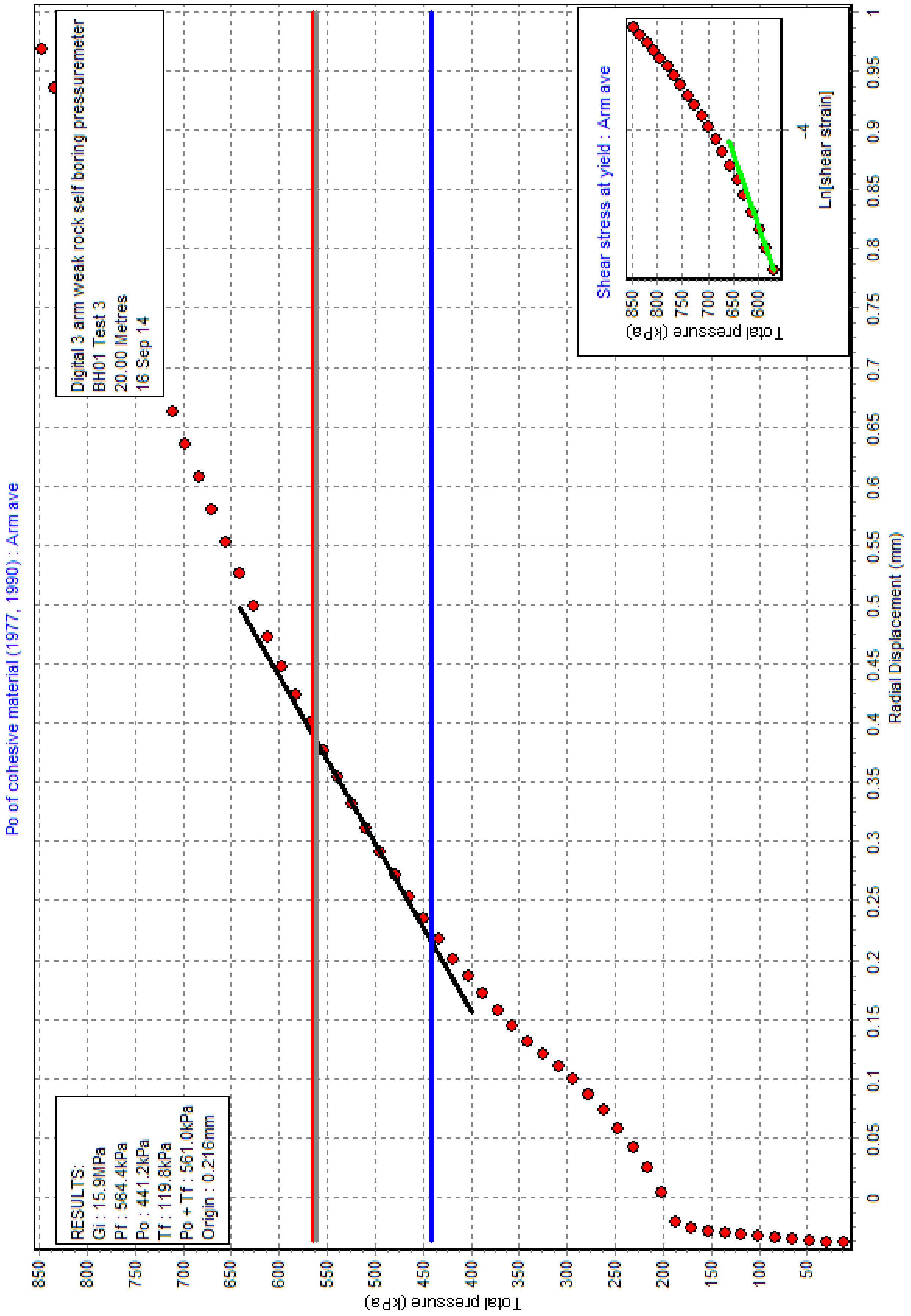

Arm Average vs Total Pressure
B01T3
20.0 metres
16/09/14
Pressure (kPa)
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1,000
1,050
1,100
1,150
1,200
1,250
1,300
1,350
1,400
Radial Displacement (mm)
0
1
2
3
4
CAMBRIDGE INSITU, Little Eversden, Cambridge, CB23 1HE Tel: +44 (0)1223 262361

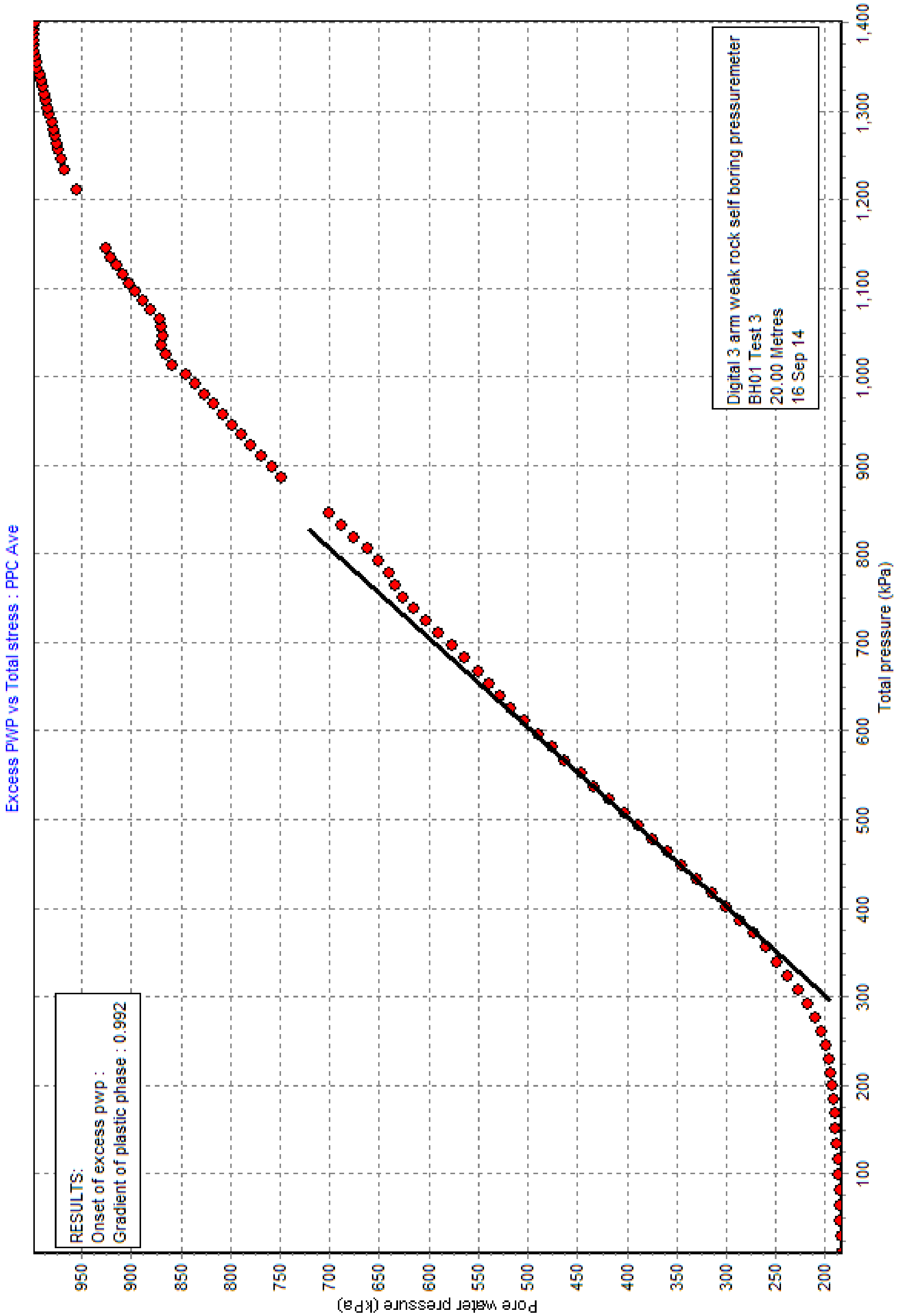

TPC
PPC A
PPC B
All Pressure Cells vs Time
B01T3
20.0 metres
16/09/14
Pressure (kPa)
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1,000
1,050
1,100
1,150
1,200
1,250
1,300
1,350
1,400
Elapsed Time (minutes)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
CAMBRIDGE INSITU, Little Eversden, Cambridge, CB23 1HE Tel: +44 (0)1223 262361

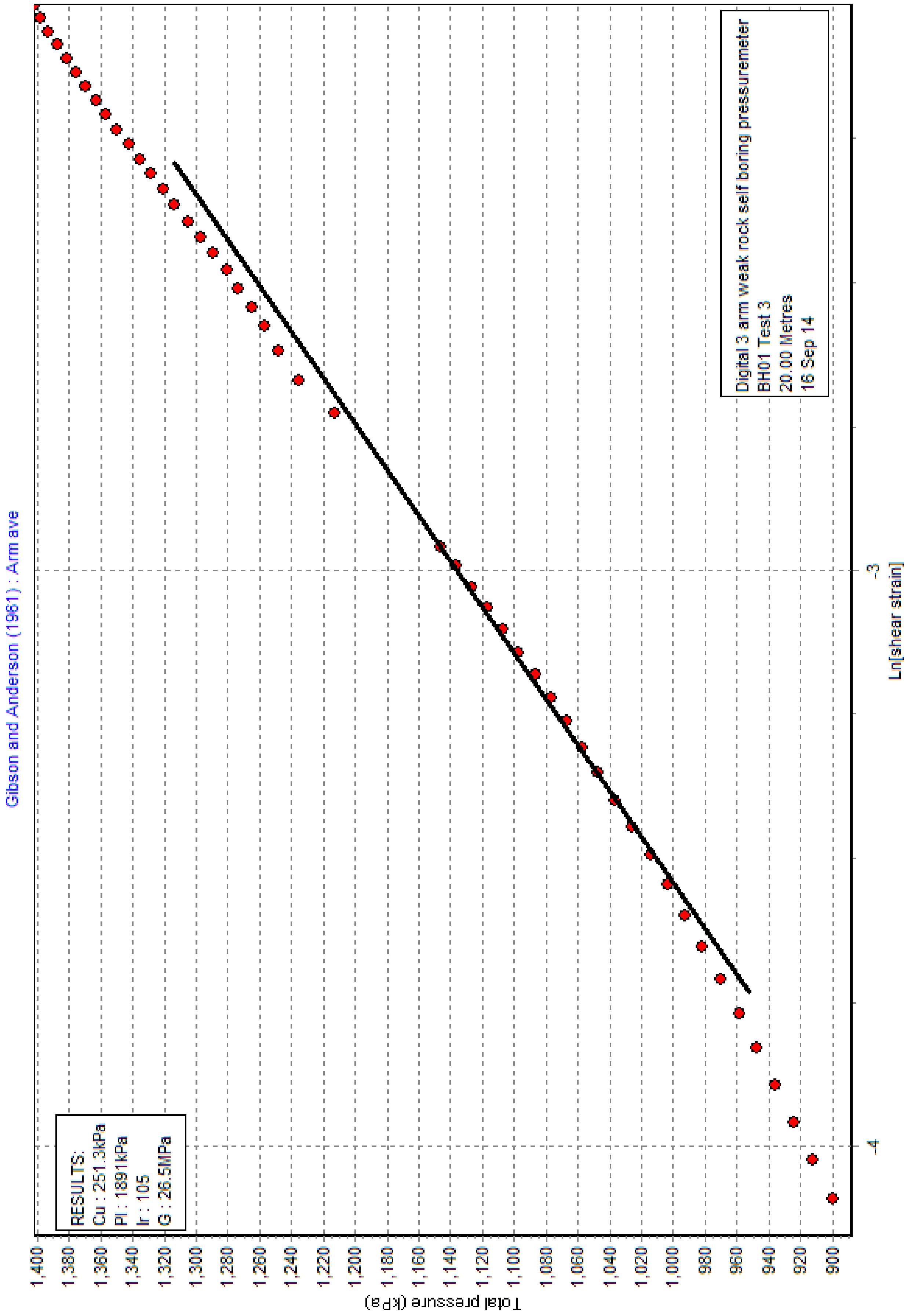
```
BH01 Test 3 - SUMMARY OF RESULTS
[File made with WinSitu  Version 3.6.1.1]

[DETAILS OF TEST]
Project        :
Site           :   1 Bedford Avenue
Borehole       :   BH01
Test name      :   BH01 Test 3
Test date      :   16 Sep 14
Test depth     :   20.00 Metres
Water table    :   Nothing entered
Ambient PWP    :   0.0 kPa
Material       :   London Clay
Probe          :   Digital 3 arm weak rock self boring pressuremeter
Diameter       :   88.1 mm
Data analysed using average arm displacement curve
A non-linear analysis of the rebound cycles has been carried out
The file includes results from a curve fitting analysis

Analysed by SDB on 14 Oct 14

Remarks:  Lost flush to hole for most of drilling. Bottom partially
blocked off.

[RESULTS FOR CAVITY REFERENCE PRESSURE]
Strain Origin (mm)                  :   "Arm ave=0.750"
Po from Marsland & Randolph (kPa)   :   "Arm ave=441.2"
Po from Lift off (kPa)              :   "Arm ave=373.9"
Best estimate of Po (kPa)           :   "Arm ave=469.0"

[UNDRAINED STRENGTH PARAMETERS]
Gibson & Anderson 1961 - Cu (kPa)   :   "Arm ave=251.3"
Limit pressure (kPa)                :   "Arm ave=1891"
Jefferies 1988 - Cu (kPa)           :   "Arm ave=251.9"
Undrained yield stress (kPa)        :   "Arm ave=564.4"

[LINEAR INTERPRETATION OF SHEAR MODULUS G]
Initial slope shear modulus (MPa) :"Arm ave=15.9"
Axis       Loop   Value    Mean Strain  Mean Pc  dE       dPc
           No     (MPa)    (%)          (kPa)    (%)      (kPa)
Arm ave    1      28.2     0.429        723      0.892    252
Arm ave    2      24.5     2.626        961      1.441    355
Arm ave    3      24.0     5.367        751      1.376    333

[UNDRAINED NON LINEAR INTERPRETATION OF SECANT SHEAR MODULUS]
Axis       Loop   Intercept  Alpha      Gradient
           No     (MPa)      (MPa)
Arm ave    1      5.535      3.595      0.649
Arm ave    2      5.563      3.585      0.644
Arm ave    3      5.329      3.394      0.637


[PARAMETERS USED FOR UNDRAINED CURVE MODELLING]
{Axis is  Arm ave}
Strain Origin (mm)                  :   0.75
Po (kPa)                            :   469
Cu (kPa)                            :   251.3
Limit pressure (kPa)                :   1891
Non-linear exponent                 :   0.637
Calculated alpha (MPa)              :   3.395
G at yield (MPa)                    :   15.0
```

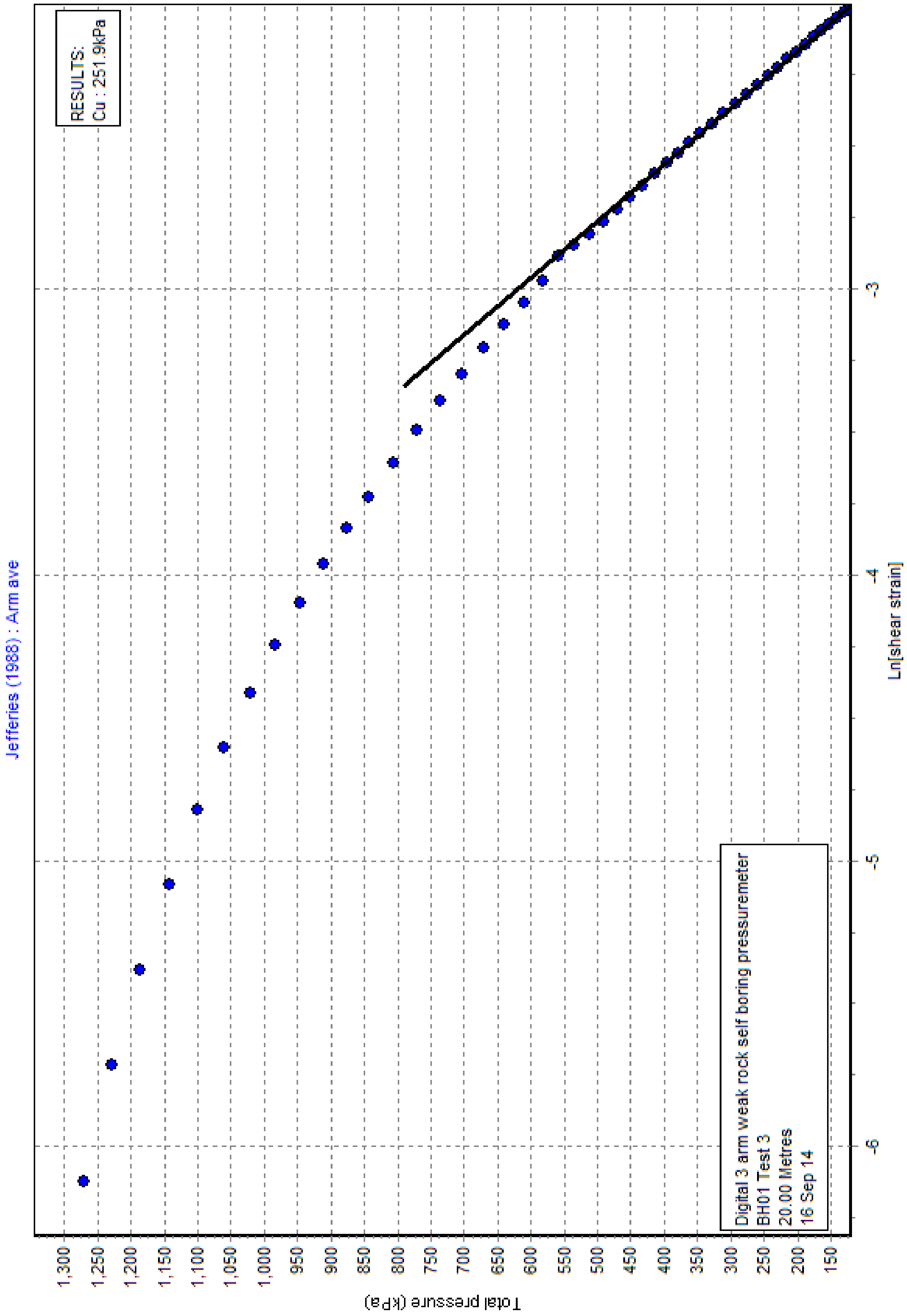

Cavity strain vs Total Pressure : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
Total pressure (kPa)
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1,000
1,050
1,100
1,150
1,200
1,250
1,300
1,350
1,400
Cavity strain (%)
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5

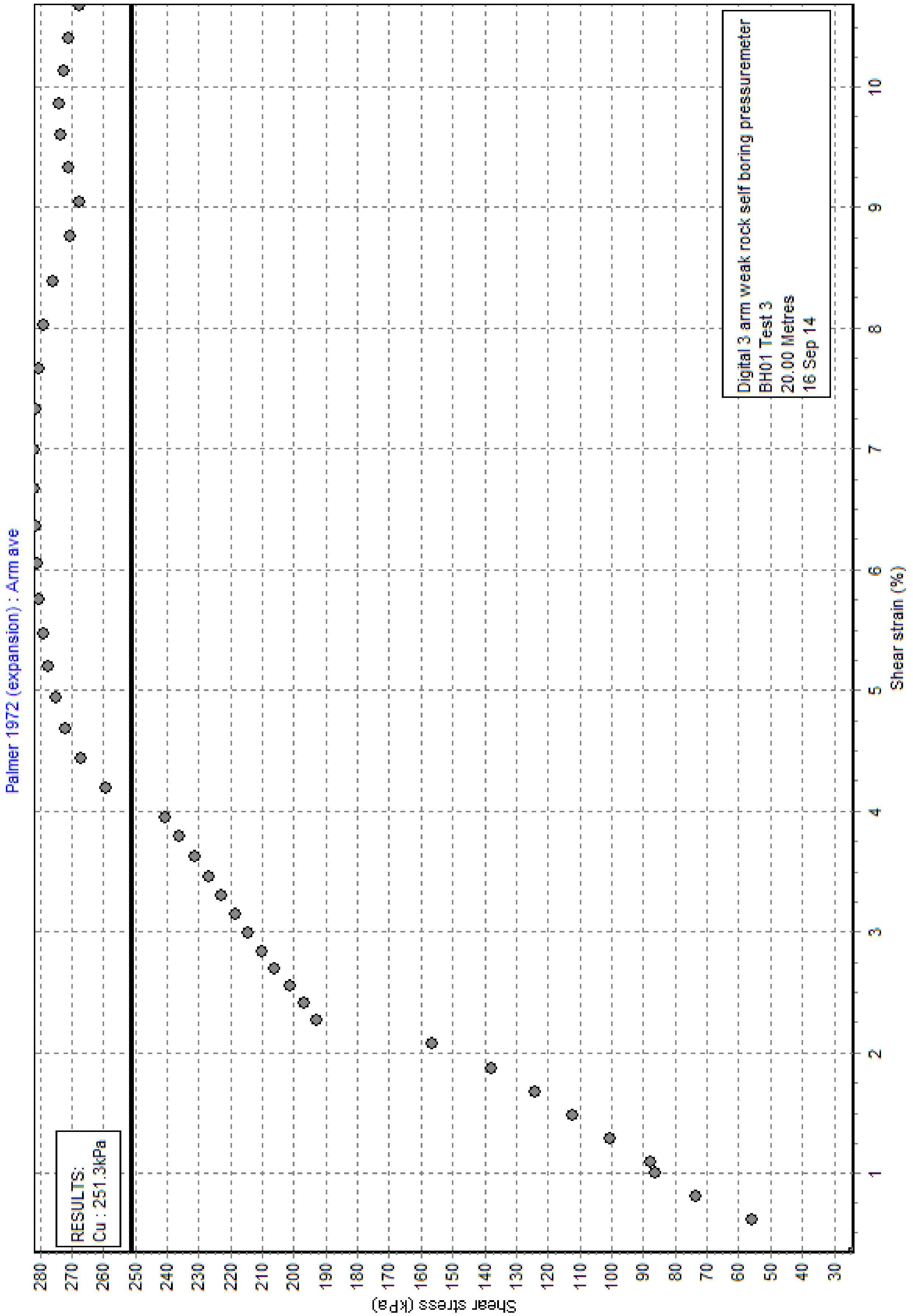

Lift-off analysis : Arm ave
RESULTS:
Lift off stress : 373.9kPa
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
Total pressure (kPa)
620
600
580
560
540
520
500
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
Radial Displacement (mm)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45

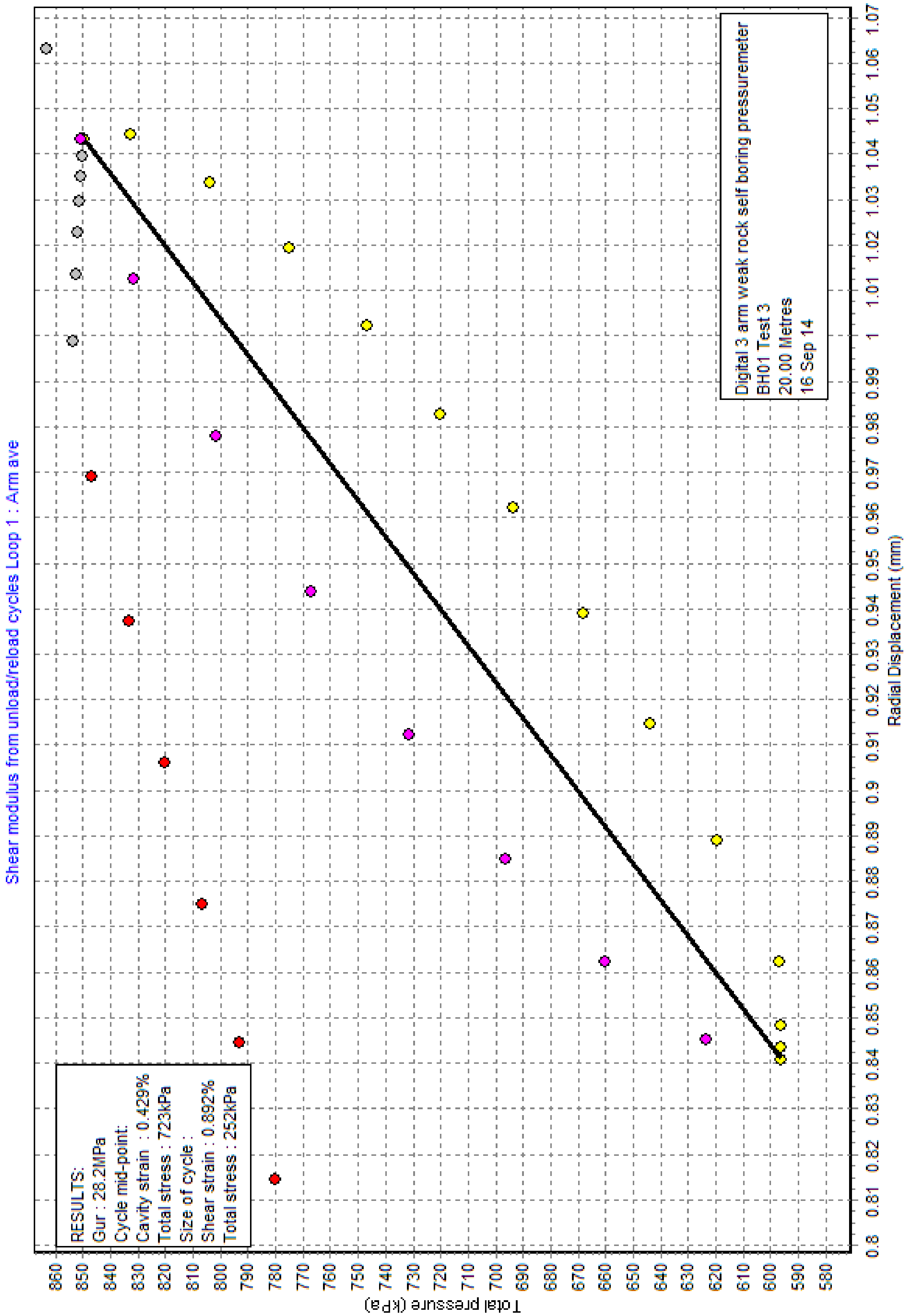

Po of cohesive material (1977 , 1990) : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
RESULTS:
Gi : 15.9MPa
Pf : 564.4kPa
Po : 441.2kPa
Tf : 119.8kPa
Po + Tf : 561.0kPa
Origin : 0.216mm
Shear stress at yield : Arm ave
Total pressure (kPa)
850
800
750
700
650
600
-4
Ln[shear strain]
Total pressure (kPa)
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
Radial Displacement (mm)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1


Excess PWP vs Total stress : PPC Ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
RESULTS:
Onset of excess pwp :
Gradient of plastic phase : 0.992
Pore water pressure (kPa)
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
Total pressure (kPa)
100
200
300
400
500
600
700
800
900
1,000
1,100
1,200
1,300
1,400


Gibson and Anderson (1961) : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
RESULTS:
Cu : 251.3kPa
Pl : 1891kPa
Ir : 105
G : 26.5MPa
Total pressure (kPa)
1,400
1,380
1,360
1,340
1,320
1,300
1,280
1,260
1,240
1,220
1,200
1,180
1,160
1,140
1,120
1,100
1,080
1,060
1,040
1,020
1,000
980
960
940
920
900
Ln[shear strain]
-3
-4


Jefferies (1988) : Arm ave
RESULTS:
Cu : 251.9kPa
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
Total pressure (kPa)
1,300
1,250
1,200
1,150
1,100
1,050
1,000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
Ln[shear strain]
-6
-5
-4
-3

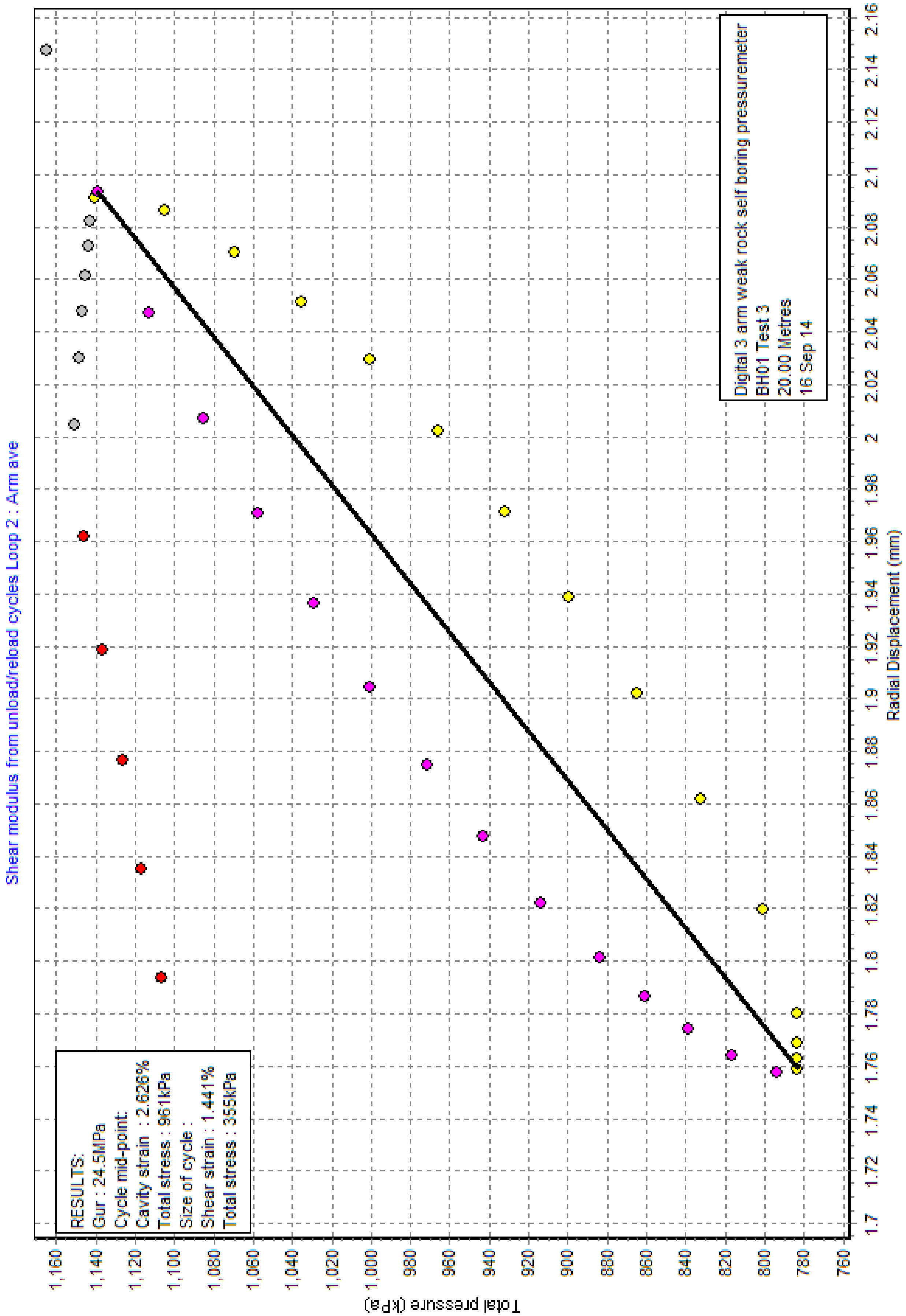

Palmer 1972 (expansion) : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
RESULTS:
Cu : 251.3kPa
Shear stress (kPa)
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
Shear strain (%)
1
2
3
4
5
6
7
8
9
10

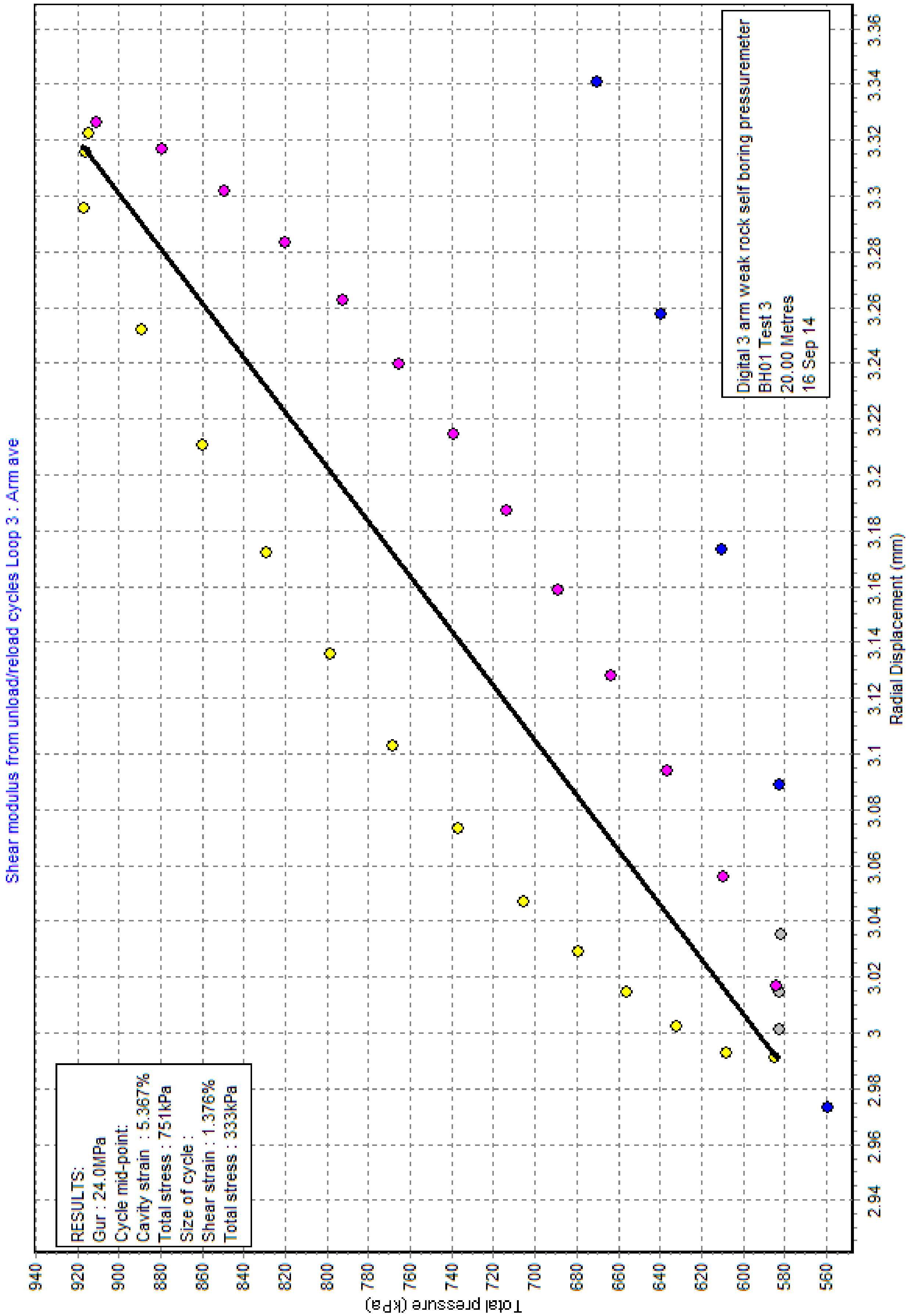


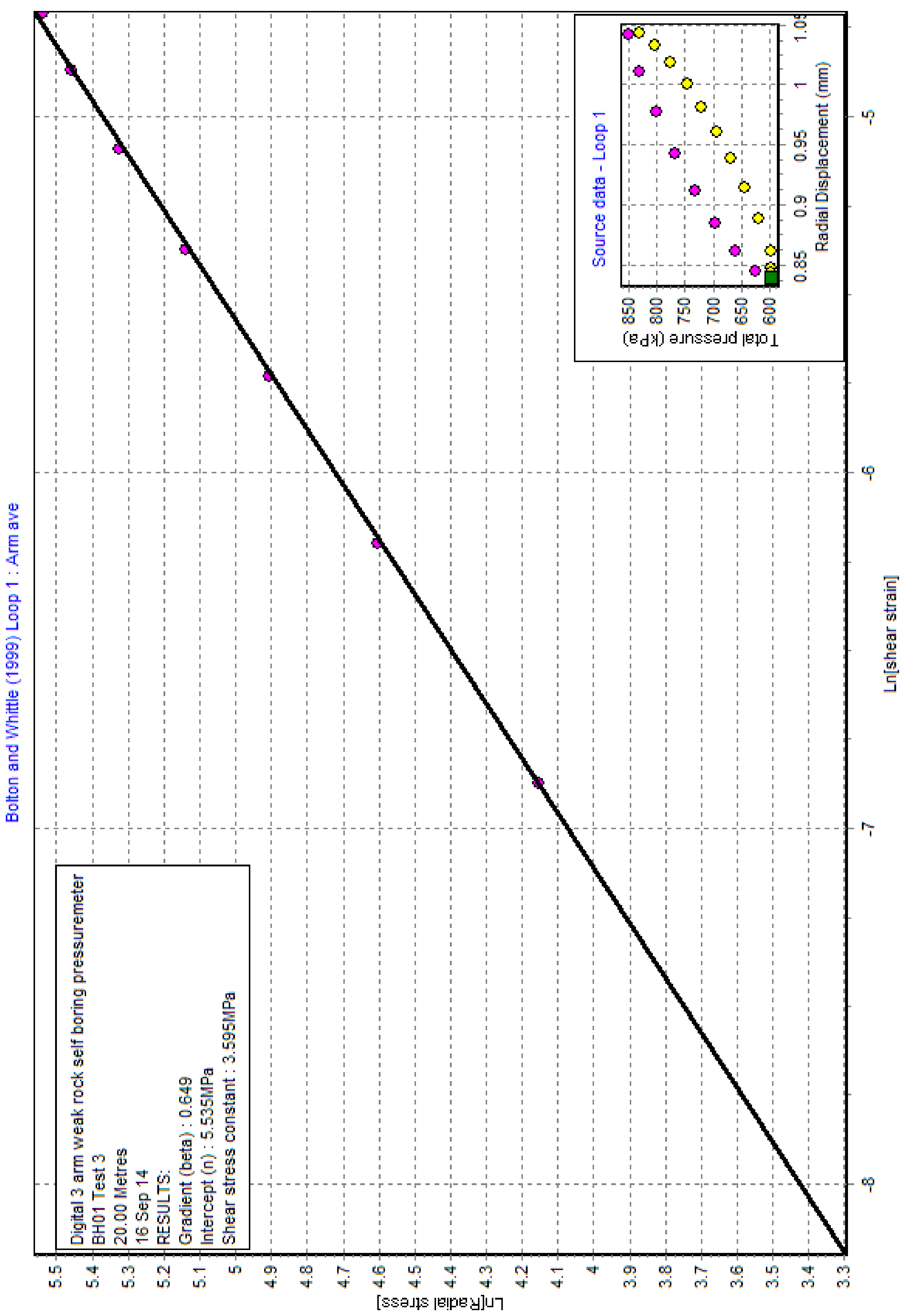
Shear modulus from unload/reload cycles Loop 1 : Arm ave

RESULTS:
Gur : 28.2MPa
Cycle mid-point:
Cavity strain : 0.429%
Total stress : 723kPa
Size of cycle :
Shear strain : 0.892%
Total stress : 252kPa

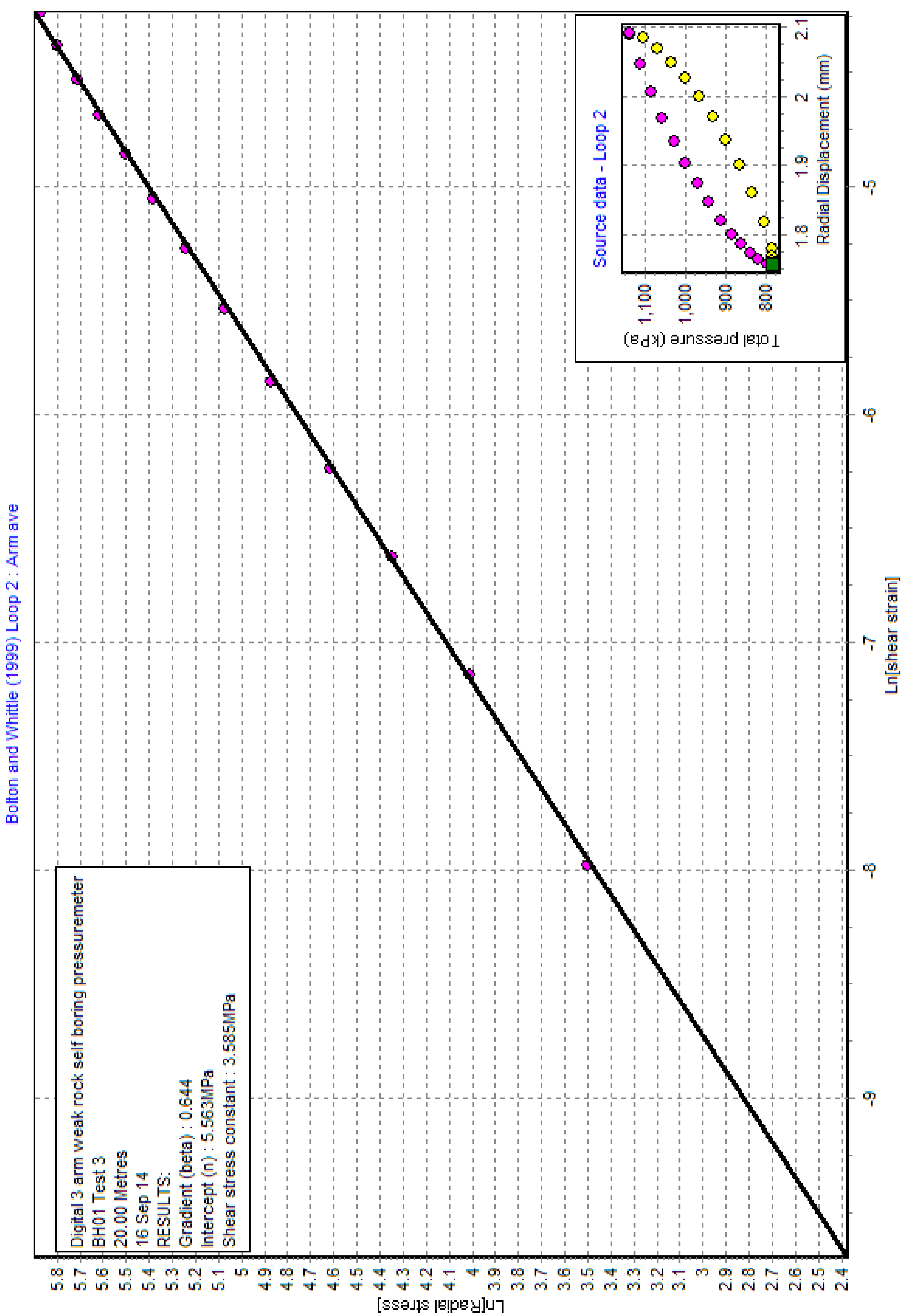
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14


Shear modulus from unload/reload cycles Loop 2 : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
RESULTS:
Gur : 24.5MPa
Cycle mid-point:
Cavity strain : 2.626%
Total stress : 961kPa
Size of cycle :
Shear strain : 1.441%
Total stress : 355kPa
Radial Displacement (mm)
1.7
1.72
1.74
1.76
1.78
1.8
1.82
1.84
1.86
1.88
1.9
1.92
1.94
1.96
1.98
2
2.02
2.04
2.06
2.08
2.1
2.12
2.14
2.16
Total pressure (kPa)
1,160
1,140
1,120
1,100
1,080
1,060
1,040
1,020
1,000
980
960
940
920
900
880
860
840
820
800
780
760

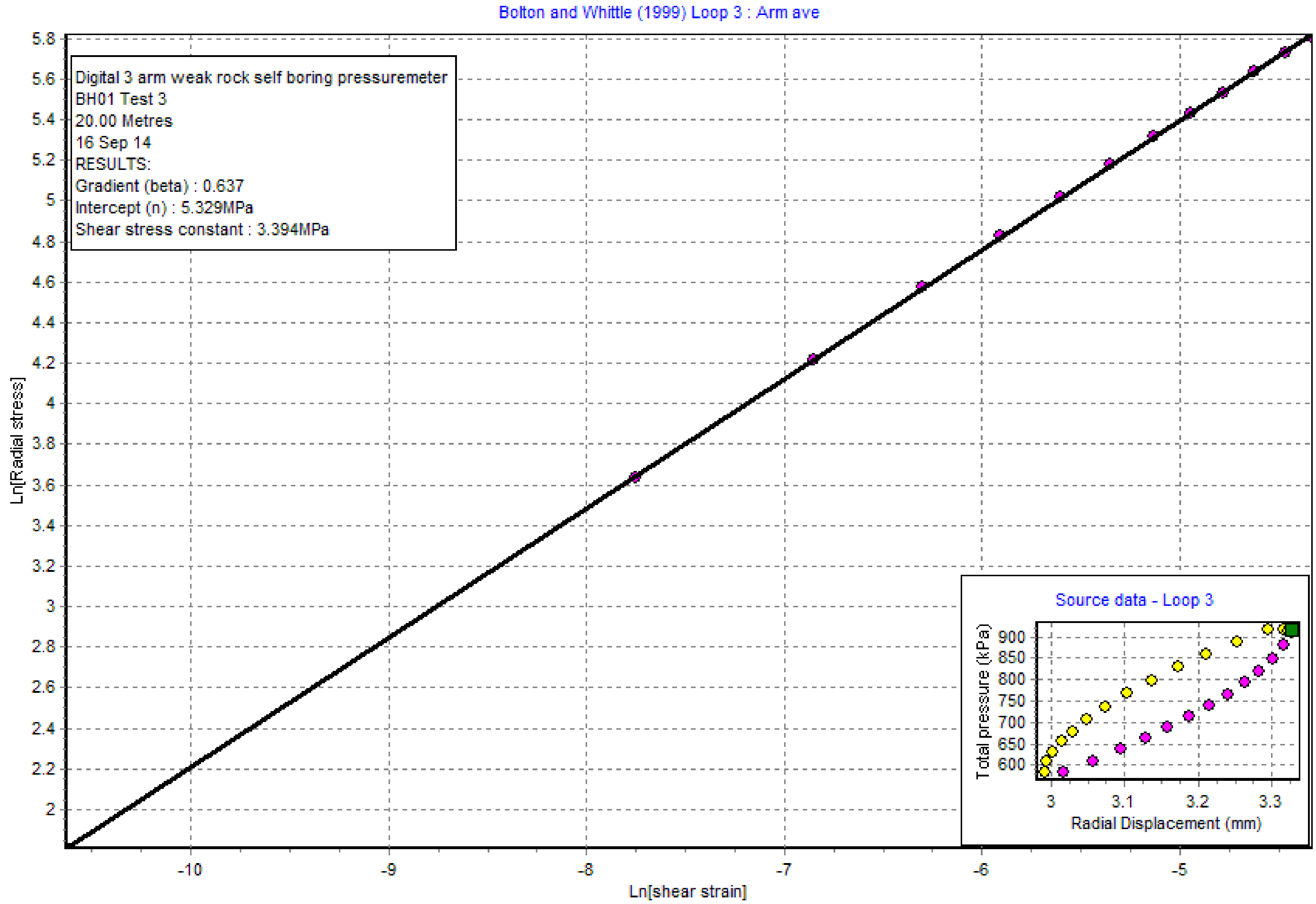

Shear modulus from unload/reload cycles Loop 3 : Arm ave
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
RESULTS:
Gur : 24.0MPa
Cycle mid-point:
Cavity strain : 5.367%
Total stress : 751kPa
Size of cycle :
Shear strain : 1.376%
Total stress : 333kPa
Radial Displacement (mm)
2.94
2.96
2.98
3
3.02
3.04
3.06
3.08
3.1
3.12
3.14
3.16
3.18
3.2
3.22
3.24
3.26
3.28
3.3
3.32
3.34
3.36
Total pressure (kPa)
940
920
900
880
860
840
820
800
780
760
740
720
700
680
660
640
620
600
580
560



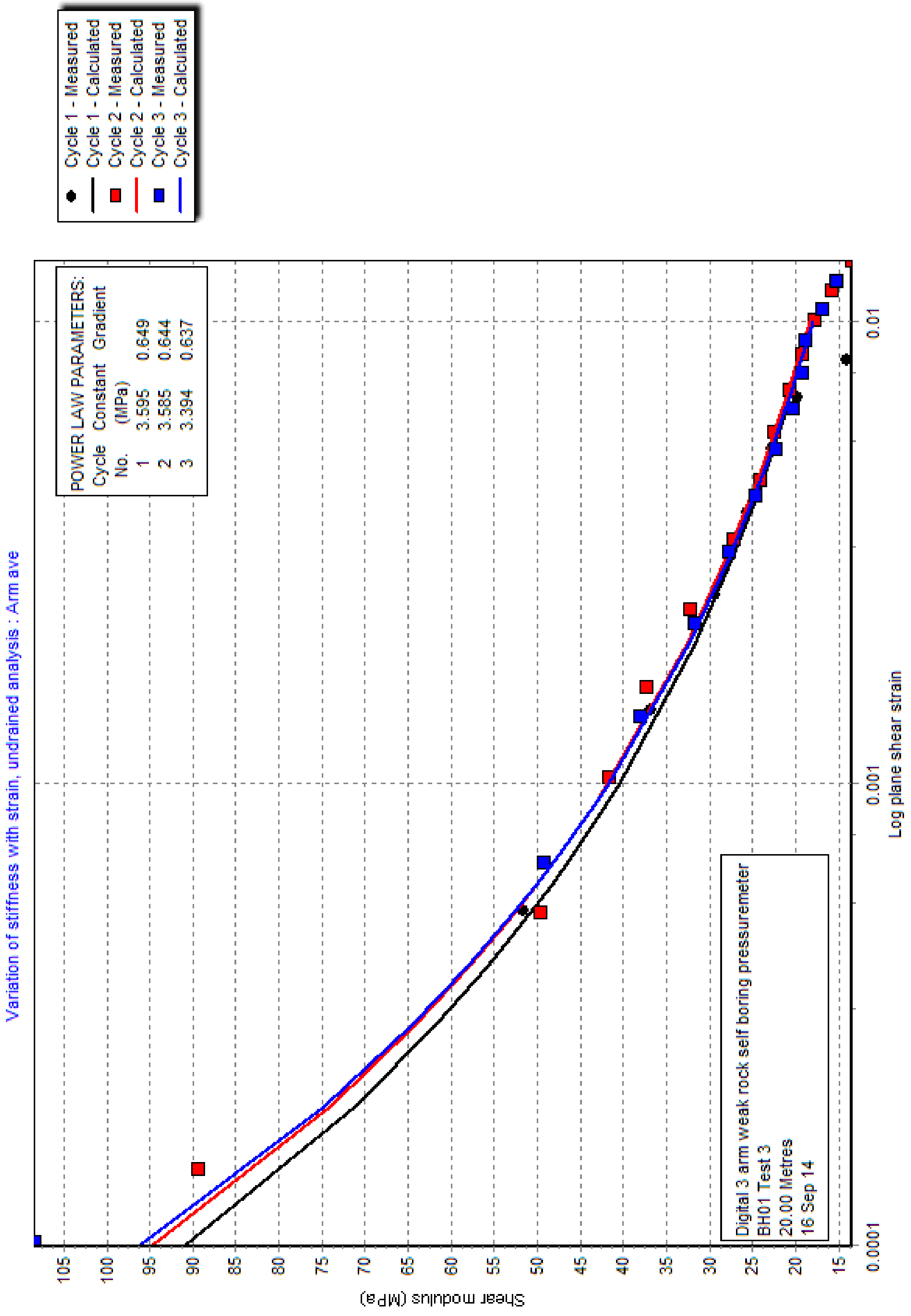
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
RESULTS:
Gradient (beta) : 0.649
Intercept (n) : 5.535MPa
Shear stress constant : 3.595MPa

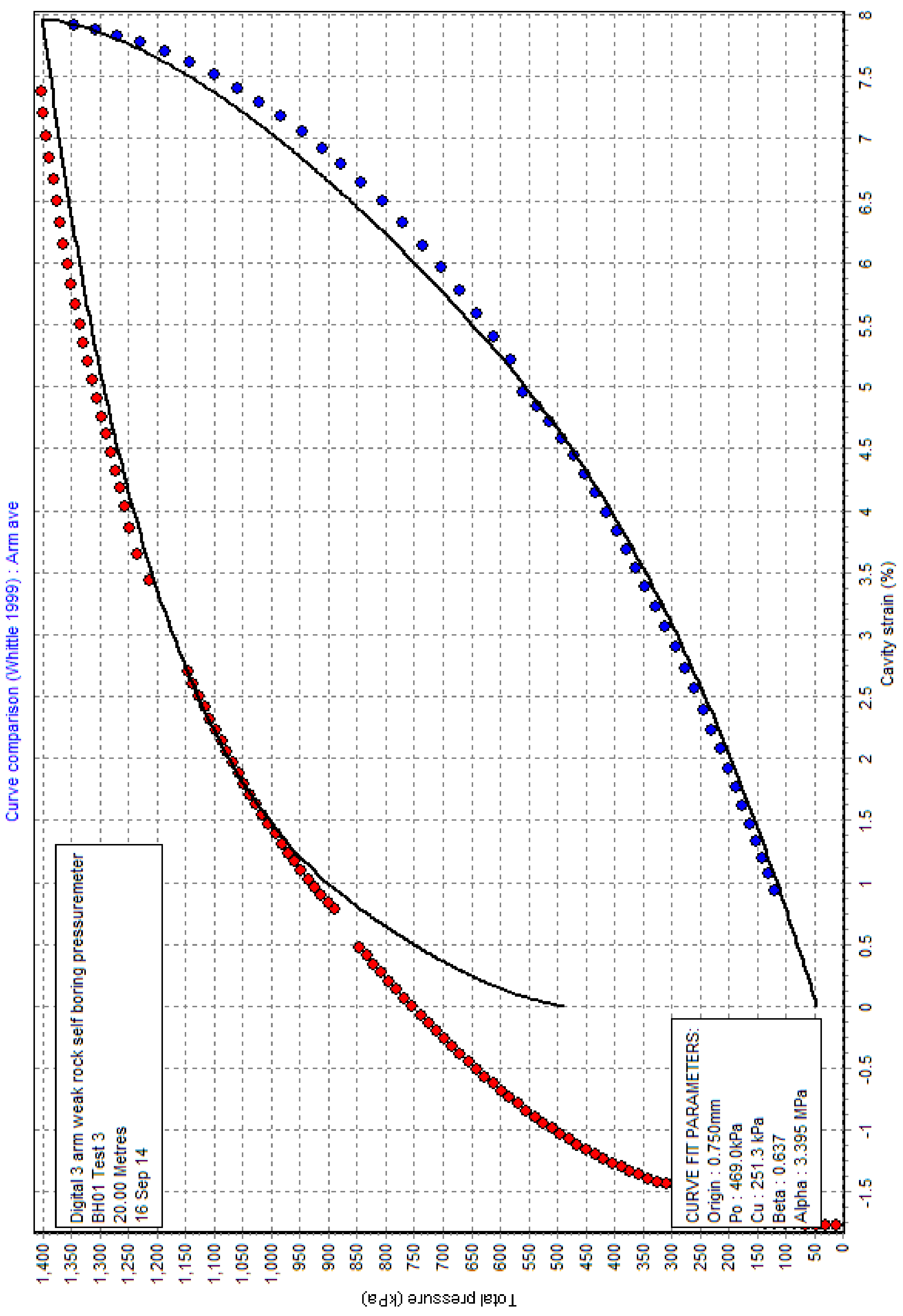


Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
RESULTS:
Gradient (beta) : 0.644
Intercept (n) : 5.563MPa
Shear stress constant : 3.585MPa

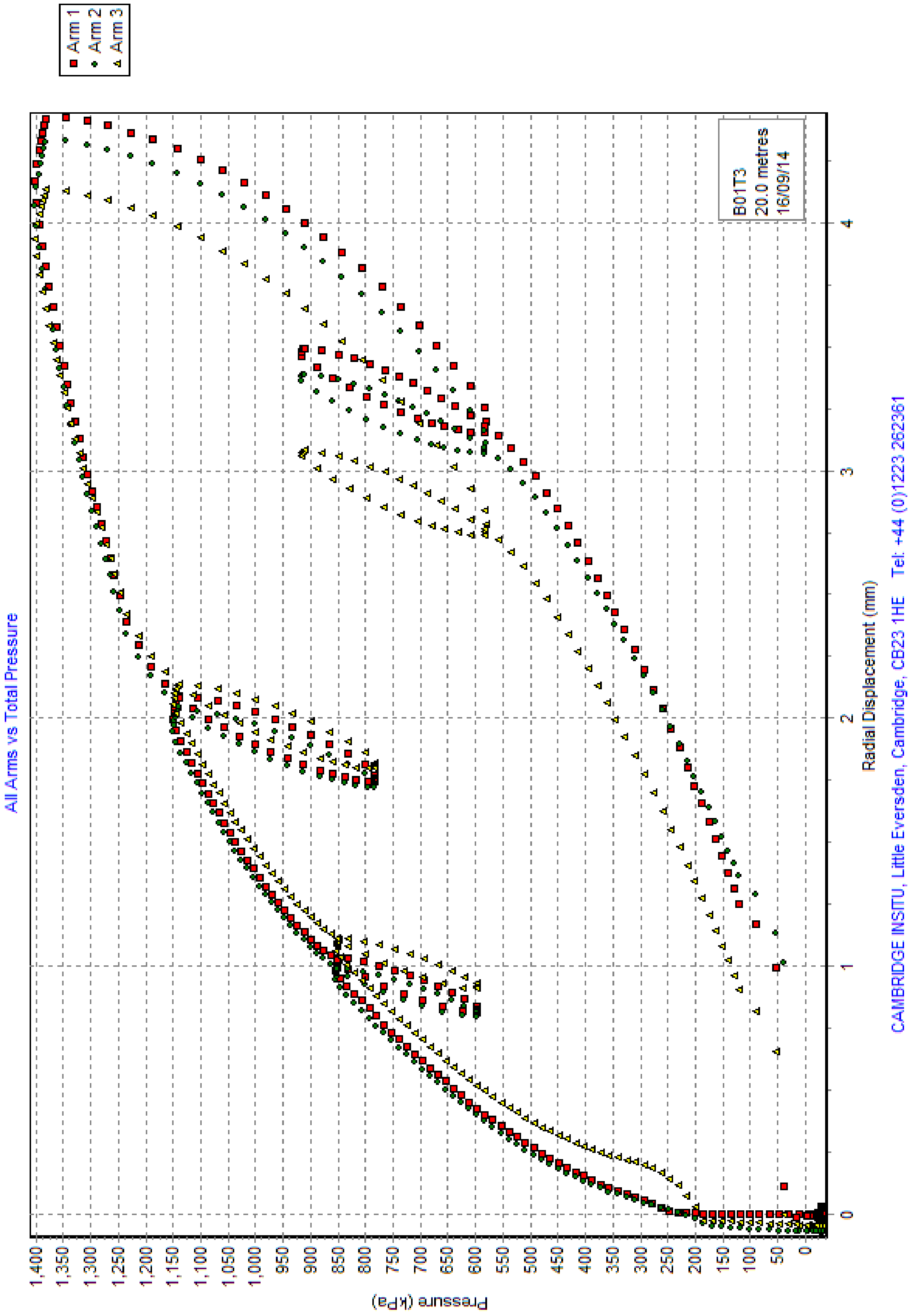


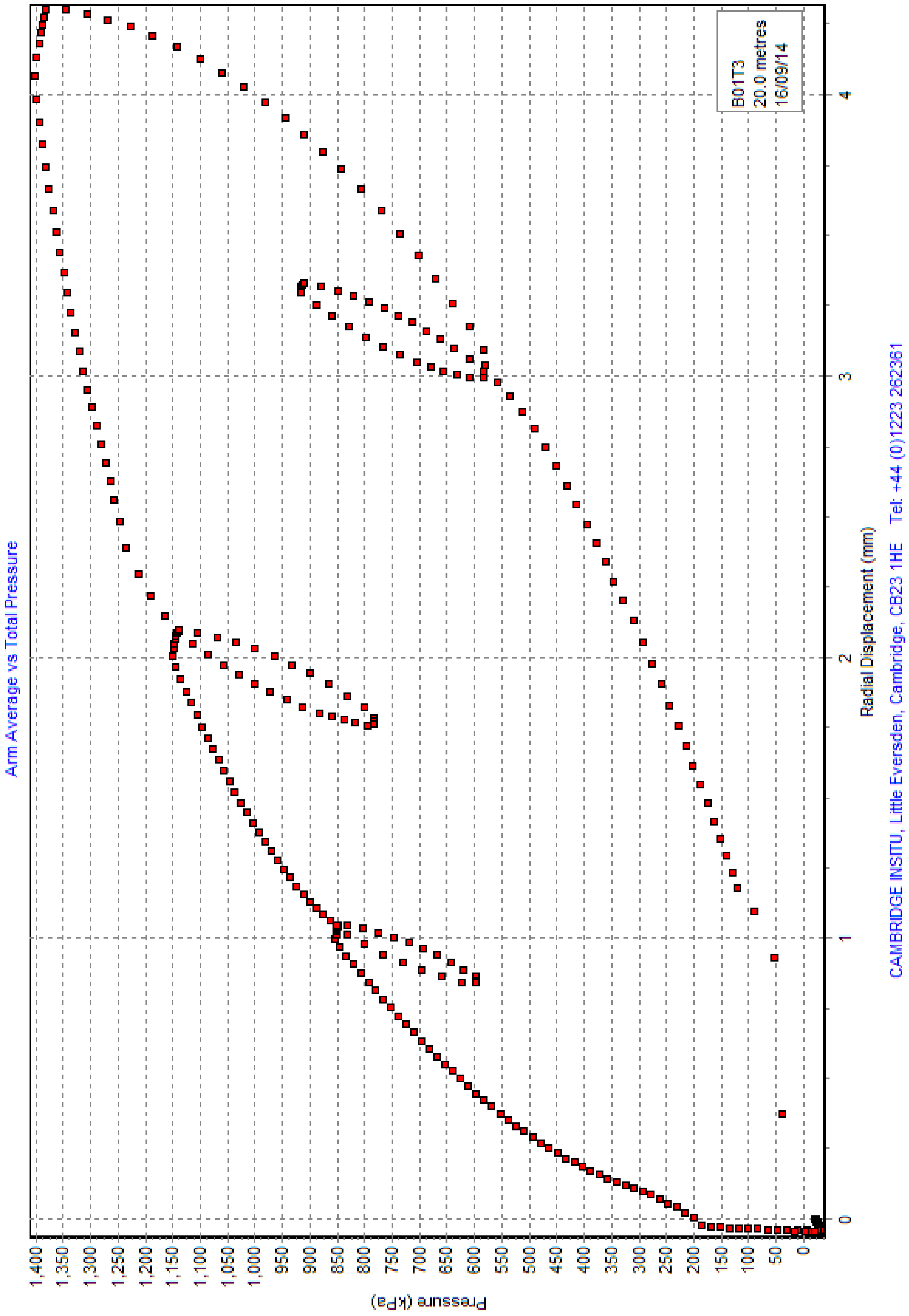
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
RESULTS:
Gradient (beta) : 0.637
Intercept (n) : 5.329MPa
Shear stress constant : 3.394MPa

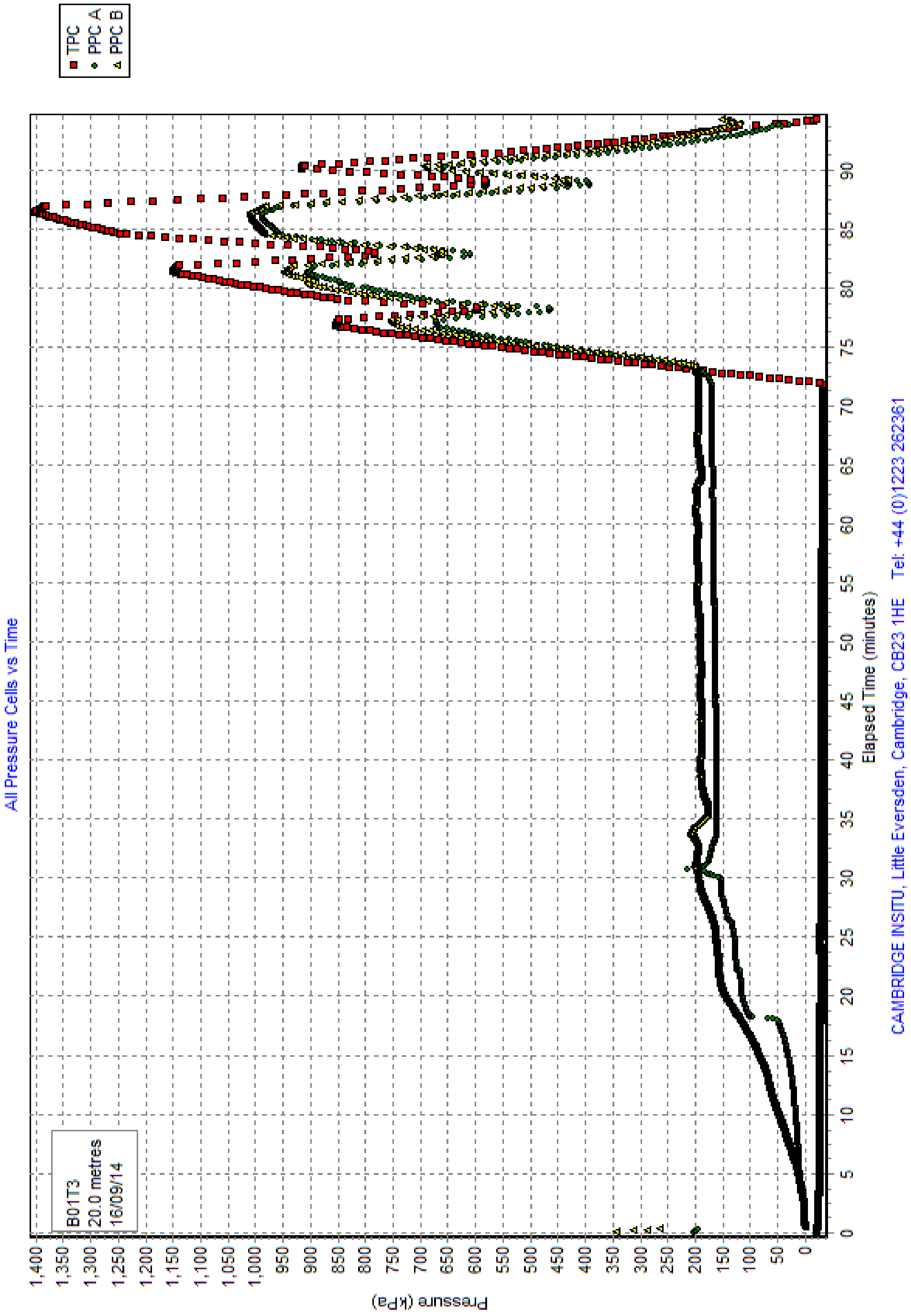

Variation of stiffness with strain, undrained analysis : Arm ave
Cycle 1 - Measured
Cycle 1 - Calculated
Cycle 2 - Measured
Cycle 2 - Calculated
Cycle 3 - Measured
Cycle 3 - Calculated
POWER LAW PARAMETERS:
Cycle No. | Constant (MPa) | Gradient
1 | 3.595 | 0.649
2 | 3.585 | 0.644
3 | 3.394 | 0.637
Digital 3 arm weak rock self boring pressuremeter
BH01 Test 3
20.00 Metres
16 Sep 14
Shear modulus (MPa)
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
Log plane shear strain
0.0001
0.001
0.01



CURVE FIT PARAMETERS:
Origin : 0.750mm
Po : 469.0kPa
Cu : 251.3 kPa
Beta : 0.637
Alpha : 3.395 MPa


All Arms vs Total Pressure
Arm 1
Arm 2
Arm 3
B01T3
20.0 metres
16/09/14
Pressure (kPa)
1,400
1,350
1,300
1,250
1,200
1,150
1,100
1,050
1,000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Radial Displacement (mm)
0
1
2
3
4
CAMBRIDGE INSITU, Little Eversden, Cambridge, CB23 1HE Tel: +44 (0)1223 262361


Arm Average vs Total Pressure
B01T3
20.0 metres
16/09/14
Pressure (kPa)
1,400
1,350
1,300
1,250
1,200
1,150
1,100
1,050
1,000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Radial Displacement (mm)
0
1
2
3
4
CAMBRIDGE INSITU, Little Eversden, Cambridge, CB23 1HE Tel: +44 (0)1223 262361


All Pressure Cells vs Time
TPC
PPC A
PPC B
B01T3
20.0 metres
16/09/14
Pressure (kPa)
1,400 1,350 1,300 1,250 1,200 1,150 1,100 1,050 1,000 950 900 850 800 750 700 650 600 550 500 450 400 350 300 250 200 150 100 50 0
Elapsed Time (minutes)
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90
CAMBRIDGE INSITU, Little Eversden, Cambridge, CB23 1HE Tel: +44 (0)1223 262361

APPENDIX D

Contamination and soluble sulphate / pH results (QTS Environmental)

- 14-24916
- 14-25327
- 14-25397
- 14-25909
- 14-26770

John Bartley
Soil Consultants Ltd
8 Haven House
Albemarle Street
Harwich
Essex
CO12 3HL

QTS Environmental Ltd
Unit 1
Rose Lane Industrial Estate
Rose Lane
Lenham Heath
Kent
ME17 2JN
t: 01622 850410
russell.jarvis@qtsenvironmental.com

QTS Environmental Report No: 14-24916

Site Reference: Bedford Avenue

Project / Job Ref: None Supplied

Order No: None Supplied

Sample Receipt Date: 15/09/2014

Sample Scheduled Date: 17/09/2014

Report Issue Number: 1

Reporting Date: 24/09/2014

Authorised by:

Russell Jarvis
Director
On behalf of QTS Environmental Ltd

Authorised by:

Kevin Old
Director
On behalf of QTS Environmental Ltd

Soil Analysis Certificate						
QTS Environmental Report No: 14-24916	**Date Sampled**	None Supplied	None Supplied	None Supplied		
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied	None Supplied		
Site Reference: Bedford Avenue	**TP / BH No**	BH1	BH1	BH1		
Project / Job Ref: None Supplied	**Additional Refs**	D1	D2	None Supplied		
Order No: None Supplied	**Depth (m)**	3.70	4.05	6.05		
Reporting Date: 24/09/2014	**QTSE Sample No**	118337	118338	118339		

Determinand	**Unit**	**RL**	**Accreditation**					
Asbestos Screen	N/a	N/a	**ISO17025**	Not Detected	Not Detected	Not Detected		
pH	pH Units	N/a	**MCERTS**	7.4	7.9	8.0		
W/S Sulphate as SO4 (2:1)	g/l	< 0.01	**MCERTS**	1.54	0.25	0.02		
Elemental Sulphur	mg/kg	< 10	NONE	< 10	< 10	< 10		
Sulphide	mg/kg	< 5	NONE	< 5	< 5	< 5		
Total Organic Carbon (TOC)	%	< 0.1	NONE	0.8	0.6	< 0.1		
Arsenic (As)	mg/kg	< 2	**MCERTS**	12	8	< 2		
Beryllium (Be)	mg/kg	< 0.5	NONE	0.5	< 0.5	< 0.5		
W/S Boron	mg/kg	< 1	NONE	< 1	< 1	< 1		
Cadmium (Cd)	mg/kg	< 0.5	**MCERTS**	< 0.5	< 0.5	< 0.5		
Chromium (Cr)	mg/kg	< 2	**MCERTS**	35	25	6		
Chromium (hexavalent)	mg/kg	< 2	NONE	< 2	< 2	< 2		
Copper (Cu)	mg/kg	< 4	**MCERTS**	52	33	< 4		
Lead (Pb)	mg/kg	< 3	**MCERTS**	91	92	6		
Mercury (Hg)	mg/kg	< 1	NONE	1.6	1.2	< 1		
Nickel (Ni)	mg/kg	< 3	**MCERTS**	46	24	6		
Selenium (Se)	mg/kg	< 3	NONE	< 3	< 3	< 3		
Vanadium (V)	mg/kg	< 2	NONE	61	46	12		
Zinc (Zn)	mg/kg	< 3	**MCERTS**	62	50	15		
Total Phenols (monohydric)	mg/kg	< 2	NONE	< 2	< 2	< 2		

Analytical results are expressed on a dry weight basis where samples are dried at less than 30^{O}C

Analysis carried out on the dried sample is corrected for the stone content

The samples have been examined to identify the presence of asbestiform minerals by polarising light microscopy and dispersion staining technique to In-House Procedures QTSE600 Determination of Asbestos in Bulk Materials; Asbestos in Soils/Sediments (fibre screening and identification)

This report refers to samples as received, and QTS Environmental Ltd, takes no responsibility for the accuracy or competence of sampling by others.

The material description shall be regarded as tentative and is not included in our scope of UKAS Accreditation.

Opinions and interpretations expressed herein are outside the scope of UKAS Accreditation.

Asbestos Analyst: Graham Revell

RL: Reporting Limit

Pinch Test: Where pinch test is positive it is reported “Loose Fibres - PT” with type(s).

Subcontracted analysis $^{(S)}$

Soil Analysis Certificate - Speciated PAHs

QTS Environmental Report No: 14-24916	**Date Sampled**	None Supplied	None Supplied	None Supplied		
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied	None Supplied		
Site Reference: Bedford Avenue	**TP / BH No**	BH1	BH1	BH1		
Project / Job Ref: None Supplied	**Additional Refs**	D1	D2	None Supplied		
Order No: None Supplied	**Depth (m)**	3.70	4.05	6.05		
Reporting Date: 24/09/2014	**QTSE Sample No**	118337	118338	118339		

Determinand	**Unit**	**RL**	**Accreditation**					
Naphthalene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Acenaphthylene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Acenaphthene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Fluorene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Phenanthrene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Anthracene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Fluoranthene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Pyrene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Benzo(a)anthracene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Chrysene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Benzo(b)fluoranthene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Benzo(k)fluoranthene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Benzo(a)pyrene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Indeno(1,2,3-cd)pyrene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Dibenz(a,h)anthracene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Benzo(ghi)perylene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Coronene	mg/kg	< 0.1	NONE	< 0.1	< 0.1	< 0.1		
Total Oily Waste PAHs	mg/kg	< 1	**MCERTS**	< 1	< 1	< 1		
Total Dutch 10 PAHs	mg/kg	< 1	**MCERTS**	< 1	< 1	< 1		
Total EPA-16 PAHs	mg/kg	< 1.6	**MCERTS**	< 1.6	< 1.6	< 1.6		
Total WAC-17 PAHs	mg/kg	< 1.7	NONE	< 1.7	< 1.7	< 1.7		

Analytical results are expressed on a dry weight basis where samples are dried at less than 30^{O}C

Soil Analysis Certificate - EPH Oily Waste Banded						
QTS Environmental Report No: 14-24916	**Date Sampled**	None Supplied	None Supplied	None Supplied		
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied	None Supplied		
Site Reference: Bedford Avenue	**TP / BH No**	BH1	BH1	BH1		
Project / Job Ref: None Supplied	**Additional Refs**	D1	D2	None Supplied		
Order No: None Supplied	**Depth (m)**	3.70	4.05	6.05		
Reporting Date: 24/09/2014	**QTSE Sample No**	118337	118338	118339		

Determinand	**Unit**	**RL**	**Accreditation**					
Oily Waste (C6 - C10)	mg/kg	< 1	NONE	< 1	< 1	< 1		
Oily Waste (>C10 - C25)	mg/kg	< 1	**MCERTS**	23	< 1	< 1		
Oily Waste (>C25 - C40)	mg/kg	< 6	**MCERTS**	46	< 6	< 6		
Oily Waste (C6 - C40)	mg/kg	< 6	NONE	69	< 6	< 6		

Analytical results are expressed on a dry weight basis where samples are dried at less than 30^{O}C

Soil Analysis Certificate - TPH CWG Banded

QTS Environmental Report No: 14-24916	**Date Sampled**	None Supplied	None Supplied	None Supplied		
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied	None Supplied		
Site Reference: Bedford Avenue	**TP / BH No**	BH1	BH1	BH1		
Project / Job Ref: None Supplied	**Additional Refs**	D1	D2	None Supplied		
Order No: None Supplied	**Depth (m)**	3.70	4.05	6.05		
Reporting Date: 24/09/2014	**QTSE Sample No**	118337	118338	118339		

Determinand	**Unit**	**RL**	**Accreditation**					
Aliphatic >C5 - C6	mg/kg	< 0.01	NONE	< 0.01	< 0.01	< 0.01		
Aliphatic >C6 - C8	mg/kg	< 0.05	NONE	< 0.05	< 0.05	< 0.05		
Aliphatic >C8 - C10	mg/kg	< 1	NONE	< 1	< 1	< 1		
Aliphatic >C10 - C12	mg/kg	< 1	NONE	< 1	< 1	< 1		
Aliphatic >C12 - C16	mg/kg	< 1	NONE	< 1	< 1	< 1		
Aliphatic >C16 - C21	mg/kg	< 1	NONE	2	< 1	< 1		
Aliphatic >C21 - C34	mg/kg	< 6	NONE	15	< 6	< 6		
Aliphatic (C5 - C34)	mg/kg	< 12	NONE	17	< 12	< 12		
Aromatic >C5 - C7	mg/kg	< 0.01	NONE	< 0.01	< 0.01	< 0.01		
Aromatic >C7 - C8	mg/kg	< 0.05	NONE	< 0.05	< 0.05	< 0.05		
Aromatic >C8 - C10	mg/kg	< 1	NONE	< 1	< 1	< 1		
Aromatic >C10 - C12	mg/kg	< 1	NONE	< 1	< 1	< 1		
Aromatic >C12 - C16	mg/kg	< 1	NONE	< 1	< 1	< 1		
Aromatic >C16 - C21	mg/kg	< 1	NONE	2	< 1	< 1		
Aromatic >C21 - C35	mg/kg	< 6	NONE	14	< 6	< 6		
Aromatic (C5 - C35)	mg/kg	< 12	NONE	17	< 12	< 12		
Total >C5 - C35	mg/kg	< 24	NONE	34	< 24	< 24		

Analytical results are expressed on a dry weight basis where samples are dried at less than 30^{O}C

Soil Analysis Certificate - BTEX / MTBE						
QTS Environmental Report No: 14-24916	**Date Sampled**	None Supplied	None Supplied	None Supplied		
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied	None Supplied		
Site Reference: Bedford Avenue	**TP / BH No**	BH1	BH1	BH1		
Project / Job Ref: None Supplied	**Additional Refs**	D1	D2	None Supplied		
Order No: None Supplied	**Depth (m)**	3.70	4.05	6.05		
Reporting Date: 24/09/2014	**QTSE Sample No**	118337	118338	118339		

Determinand	**Unit**	**RL**	**Accreditation**					
Benzene	ug/kg	< 2	**MCERTS**	< 2	< 2	< 2		
Toluene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
Ethylbenzene	ug/kg	< 10	**MCERTS**	< 10	< 10	< 10		
p & m-xylene	ug/kg	< 10	**MCERTS**	< 10	< 10	< 10		
o-xylene	ug/kg	< 10	**MCERTS**	< 10	< 10	< 10		
MTBE	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		

Analytical results are expressed on a dry weight basis where samples are dried at less than 30^{O}C

QTS Environmental Ltd
Unit 1, Rose Lane Industrial Estate
Rose Lane
Lenham Heath
Maidstone
Kent ME17 2JN
Tel : 01622 850410

Soil Analysis Certificate - Volatile Organic Compounds (VOC)

QTS Environmental Report No: 14-24916	**Date Sampled**	None Supplied	None Supplied	None Supplied		
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied	None Supplied		
Site Reference: Bedford Avenue	**TP / BH No**	BH1	BH1	BH1		
Project / Job Ref: None Supplied	**Additional Refs**	D1	D2	None Supplied		
Order No: None Supplied	**Depth (m)**	3.70	4.05	6.05		
Reporting Date: 24/09/2014	**QTSE Sample No**	118337	118338	118339		

Determinand	**Unit**	**RL**	**Accreditation**					
Dichlorodifluoromethane	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
Vinyl Chloride	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
Chloromethane	ug/kg	< 10	**MCERTS**	< 10	< 10	< 10		
Chloroethane	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
Bromomethane	ug/kg	< 10	**MCERTS**	< 10	< 10	< 10		
Trichlorofluoromethane	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
1,1-Dichloroethene	ug/kg	< 5	**ISO17025**	< 5	< 5	< 5		
MTBE	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
trans-1,2-Dichloroethene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
1,1-Dichloroethane	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
cis-1,2-Dichloroethene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
2,2-Dichloropropane	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
Chloroform	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
Bromochloromethane	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
1,1,1-Trichloroethane	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
1,1-Dichloropropene	ug/kg	< 10	**MCERTS**	< 10	< 10	< 10		
Carbon Tetrachloride	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
1,2-Dichloroethane	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
Benzene	ug/kg	< 2	**MCERTS**	< 2	< 2	< 2		
1,2-Dichloropropane	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
Trichloroethene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
Bromodichloromethane	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
Dibromomethane	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
TAME	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
cis-1,3-Dichloropropene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
Toluene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
trans-1,3-Dichloropropene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
1,1,2-Trichloroethane	ug/kg	< 10	**MCERTS**	< 10	< 10	< 10		
1,3-Dichloropropane	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
Tetrachloroethene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
Dibromochloromethane	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
1,2-Dibromoethane	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
Chlorobenzene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
1,1,1,2-Tetrachloroethane	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
Ethyl Benzene	ug/kg	< 10	**MCERTS**	< 10	< 10	< 10		
m,p-Xylene	ug/kg	< 10	**MCERTS**	< 10	< 10	< 10		
o-Xylene	ug/kg	< 10	**MCERTS**	< 10	< 10	< 10		
Styrene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
Bromoform	ug/kg	< 10	**MCERTS**	< 10	< 10	< 10		
Isopropylbenzene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
1,1,2,2-Tetrachloroethane	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
1,2,3-Trichloropropane	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
n-Propylbenzene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
Bromobenzene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
2-Chlorotoluene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
1,3,5-Trimethylbenzene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
4-Chlorotoluene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
tert-Butylbenzene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
1,2,4-Trimethylbenzene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
sec-Butylbenzene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
p-Isopropyltoluene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
1,3-Dichlorobenzene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
1,4-Dichlorobenzene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
n-Butylbenzene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
1,2-Dichlorobenzene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		
1,2-Dibromo-3-chloropropane	ug/kg	< 10	**MCERTS**	< 10	< 10	< 10		
Hexachlorobutadiene	ug/kg	< 5	**MCERTS**	< 5	< 5	< 5		

Analytical results are expressed on a dry weight basis where samples are dried at less than 30^{O}C

Soil Analysis Certificate - Volatile Organic Compounds TIC (VOC)

QTS Environmental Report No: 14-24916		**Date Sampled**	None Supplied
Soil Consultants Ltd		**Time Sampled**	None Supplied
Site Reference: Bedford Avenue		**TP / BH No**	BH1
Project / Job Ref: None Supplied		**Additional Refs**	D1
Order No: None Supplied		**Depth (m)**	3.70
Reporting Date: 24/09/2014		**QTSE Sample No**	118337

Compound No	Compound Name	% Match	Units	RL	Estimated Concentration
1	N/a	N/a	µg/kg	< 10	< 10
2	N/a	N/a	µg/kg	< 10	< 10
3	N/a	N/a	µg/kg	< 10	< 10
4	N/a	N/a	µg/kg	< 10	< 10
5	N/a	N/a	µg/kg	< 10	< 10

There were no / other compounds identified with a match of >90%

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Soil Analysis Certificate - Volatile Organic Compounds TIC (VOC)

QTS Environmental Report No: 14-24916	**Date Sampled**	None Supplied
Soil Consultants Ltd	**Time Sampled**	None Supplied
Site Reference: Bedford Avenue	**TP / BH No**	BH1
Project / Job Ref: None Supplied	**Additional Refs**	D2
Order No: None Supplied	**Depth (m)**	4.05
Reporting Date: 24/09/2014	**QTSE Sample No**	118338

Compound No	Compound Name	% Match	Units	RL	Estimated Concentration
1	N/a	N/a	µg/kg	< 10	< 10
2	N/a	N/a	µg/kg	< 10	< 10
3	N/a	N/a	µg/kg	< 10	< 10
4	N/a	N/a	µg/kg	< 10	< 10
5	N/a	N/a	µg/kg	< 10	< 10

There were no / other compounds identified with a match of >90%

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Soil Analysis Certificate - Volatile Organic Compounds TIC (VOC)		
QTS Environmental Report No: 14-24916	**Date Sampled**	None Supplied
Soil Consultants Ltd	**Time Sampled**	None Supplied
Site Reference: Bedford Avenue	**TP / BH No**	BH1
Project / Job Ref: None Supplied	**Additional Refs**	None Supplied
Order No: None Supplied	**Depth (m)**	6.05
Reporting Date: 24/09/2014	**QTSE Sample No**	118339

Compound No	Compound Name	% Match	Units	RL	Estimated Concentration
1	N/a	N/a	µg/kg	< 10	< 10
2	N/a	N/a	µg/kg	< 10	< 10
3	N/a	N/a	µg/kg	< 10	< 10
4	N/a	N/a	µg/kg	< 10	< 10
5	N/a	N/a	µg/kg	< 10	< 10

There were no / other compounds identified with a match of >90%

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Lenham Heath
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Kent ME17 2JN
Tel : 01622 850410

Soil Analysis Certificate - Semi Volatile Organic Compounds (SVOC)

QTS Environmental Report No: 14-24916	**Date Sampled**	None Supplied	None Supplied	None Supplied		
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied	None Supplied		
Site Reference: Bedford Avenue	**TP / BH No**	BH1	BH1	BH1		
Project / Job Ref: None Supplied	**Additional Refs**	D1	D2	None Supplied		
Order No: None Supplied	**Depth (m)**	3.70	4.05	6.05		
Reporting Date: 24/09/2014	**QTSE Sample No**	118337	118338	118339		

Determinand	**Unit**	**RL**	**Accreditation**					
Phenol	mg/kg	< 0.1	NONE	< 0.1	< 0.1	< 0.1		
1,2,4-Trichlorobenzene	mg/kg	< 0.1	**ISO17025**	< 0.1	< 0.1	< 0.1		
2-Nitrophenol	mg/kg	< 0.1	NONE	< 0.1	< 0.1	< 0.1		
Nitrobenzene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
0-Cresol	mg/kg	< 0.1	NONE	< 0.1	< 0.1	< 0.1		
bis(2-chloroethoxy)methane	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
bis(2-chloroethyl)ether	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
2,4-Dichlorophenol	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
2-Chlorophenol	mg/kg	< 0.1	**ISO17025**	< 0.1	< 0.1	< 0.1		
1,3-Dichlorobenzene	mg/kg	< 0.1	**ISO17025**	< 0.1	< 0.1	< 0.1		
1,4-Dichlorobenzene	mg/kg	< 0.1	**ISO17025**	< 0.1	< 0.1	< 0.1		
1,2-Dichlorobenzene	mg/kg	< 0.1	**ISO17025**	< 0.1	< 0.1	< 0.1		
2,4-Dimethylphenol	mg/kg	< 0.15	**ISO17025**	< 0.15	< 0.15	< 0.15		
Isophorone	mg/kg	< 0.1	NONE	< 0.1	< 0.1	< 0.1		
Hexachloroethane	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
p-Cresol	mg/kg	< 0.15	**MCERTS**	< 0.15	< 0.15	< 0.15		
2,4,6-Trichlorophenol	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
2,4,5-Trichlorophenol	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
2-Nitroaniline	mg/kg	< 0.1	NONE	< 0.1	< 0.1	< 0.1		
4-Chloro-3-methylphenol	mg/kg	< 0.1	NONE	< 0.1	< 0.1	< 0.1		
2-Methylnaphthalene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Hexachlorocyclopentadiene	mg/kg	< 0.1	NONE	< 0.1	< 0.1	< 0.1		
Hexachlorobutadiene	mg/kg	< 0.1	**ISO17025**	< 0.1	< 0.1	< 0.1		
2,6-Dinitrotoluene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Dimethyl phthalate	mg/kg	< 0.1	NONE	< 0.1	< 0.1	< 0.1		
2-Chloronaphthalene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
4-Chloroanaline	mg/kg	< 0.2	NONE	< 0.2	< 0.2	< 0.2		
4-Nitrophenol	mg/kg	< 0.1	NONE	< 0.1	< 0.1	< 0.1		
4-Chlorophenyl phenyl ether	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
3-Nitroaniline	mg/kg	< 0.1	NONE	< 0.1	< 0.1	< 0.1		
4-Nitroaniline	mg/kg	< 0.1	NONE	< 0.1	< 0.1	< 0.1		
4-Bromophenyl phenyl ether	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Hexachlorobenzene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
2,4-Dinitrotoluene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Diethyl phthalate	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Dibenzofuran	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Azobenzene	mg/kg	< 0.1	NONE	< 0.1	< 0.1	< 0.1		
Dibutyl phthalate	mg/kg	< 0.15	**ISO17025**	< 0.15	< 0.15	< 0.15		
Carbazole	mg/kg	< 0.1	**ISO17025**	< 0.1	< 0.1	< 0.1		
bis(2-ethylhexyl)phthalate	mg/kg	< 0.2	**MCERTS**	< 0.2	< 0.2	< 0.2		
Benzyl butyl phthalate	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		
Di-n-octyl phthalate	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1	< 0.1		

Analytical results are expressed on a dry weight basis where samples are dried at less than 30^{O}C

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Soil Analysis Certificate - Semi Volatile Organic Compounds TIC (SVOC)

QTS Environmental Report No: 14-24916	**Date Sampled**	None Supplied
Soil Consultants Ltd	**Time Sampled**	None Supplied
Site Reference: Bedford Avenue	**TP / BH No**	BH1
Project / Job Ref: None Supplied	**Additional Refs**	D1
Order No: None Supplied	**Depth (m)**	3.70
Reporting Date: 24/09/2014	**QTSE Sample No**	118337

Compound No	Compound Name	% Match	Units	RL	Estimated Concentration
1	N/a	N/a	mg/kg	< 0.1	< 0.1
2	N/a	N/a	mg/kg	< 0.1	< 0.1
3	N/a	N/a	mg/kg	< 0.1	< 0.1
4	N/a	N/a	mg/kg	< 0.1	< 0.1
5	N/a	N/a	mg/kg	< 0.1	< 0.1

There were no / other compounds identified with a match of >90%

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Soil Analysis Certificate - Semi Volatile Organic Compounds TIC (SVOC)		
QTS Environmental Report No: 14-24916	**Date Sampled**	None Supplied
Soil Consultants Ltd	**Time Sampled**	None Supplied
Site Reference: Bedford Avenue	**TP / BH No**	BH1
Project / Job Ref: None Supplied	**Additional Refs**	D2
Order No: None Supplied	**Depth (m)**	4.05
Reporting Date: 24/09/2014	**QTSE Sample No**	118338

Compound No	Compound Name	% Match	Units	RL	Estimated Concentration
1	N/a	N/a	mg/kg	< 0.1	< 0.1
2	N/a	N/a	mg/kg	< 0.1	< 0.1
3	N/a	N/a	mg/kg	< 0.1	< 0.1
4	N/a	N/a	mg/kg	< 0.1	< 0.1
5	N/a	N/a	mg/kg	< 0.1	< 0.1

There were no / other compounds identified with a match of >90%

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Tel : 01622 850410

Soil Analysis Certificate - Semi Volatile Organic Compounds TIC (SVOC)

QTS Environmental Report No: 14-24916	**Date Sampled**	None Supplied
Soil Consultants Ltd	**Time Sampled**	None Supplied
Site Reference: Bedford Avenue	**TP / BH No**	BH1
Project / Job Ref: None Supplied	**Additional Refs**	None Supplied
Order No: None Supplied	**Depth (m)**	6.05
Reporting Date: 24/09/2014	**QTSE Sample No**	118339

Compound No	Compound Name	% Match	Units	RL	Estimated Concentration
1	N/a	N/a	mg/kg	< 0.1	< 0.1
2	N/a	N/a	mg/kg	< 0.1	< 0.1
3	N/a	N/a	mg/kg	< 0.1	< 0.1
4	N/a	N/a	mg/kg	< 0.1	< 0.1
5	N/a	N/a	mg/kg	< 0.1	< 0.1

There were no / other compounds identified with a match of >90%

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MCERTS THE ENVIRONMENT AGENCY'S MONITORING CERTIFICATION SCHEME
UKAS TESTING 4480

Soil Analysis Certificate - Sample Descriptions

QTS Environmental Report No: 14-24916
Soil Consultants Ltd
Site Reference: Bedford Avenue
Project / Job Ref: None Supplied
Order No: None Supplied
Reporting Date: 24/09/2014

QTSE Sample No	TP / BH No	Additional Refs	Depth (m)	Moisture Content (%)	Sample Matrix Description
^ 118337	BH1	D1	3.70	13	Brown loamy clay with rubble
^ 118338	BH1	D2	4.05	11.5	Brown clayey gravel with stones
^ 118339	BH1	None Supplied	6.05	15.9	Brown sandy gravel with stones

Moisture content is part of procedure E003 & is not an accredited test
Insufficient Sample $^{I/S}$
Unsuitable Sample $^{U/S}$
^ no sampling date provided; unable to confirm if samples are within acceptable holding times

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Soil Analysis Certificate - Methodology & Miscellaneous Information

QTS Environmental Report No: 14-24916
Soil Consultants Ltd
Site Reference: Bedford Avenue
Project / Job Ref: None Supplied
Order No: None Supplied
Reporting Date: 24/09/2014

Matrix	Analysed On	Determinand	Brief Method Description	Method No
Soil	D	Boron - Water Soluble	Determination of water soluble boron in soil by 2:1 hot water extract followed by ICP-OES	E012
Soil	AR	BTEX	Determination of BTEX by headspace GC-MS	E001
Soil	D	Cations	Determination of cations in soil by aqua-regia digestion followed by ICP-OES	E002
Soil	D	Chloride - Water Soluble (2:1)	Determination of chloride by extraction with water & analysed by ion chromatography	E009
Soil	AR	Chromium - Hexavalent	Determination of hexavalent chromium in soil by extraction in water then by acidification, addition of 1,5 diphenylcarbazide followed by colorimetry	E016
Soil	AR	Cyanide - Complex	Determination of complex cyanide by distillation followed by colorimetry	E015
Soil	AR	Cyanide - Free	Determination of free cyanide by distillation followed by colorimetry	E015
Soil	AR	Cyanide - Total	Determination of total cyanide by distillation followed by colorimetry	E015
Soil	D	Cyclohexane Extractable Matter (CEM)	Gravimetrically determined through extraction with cyclohexane	E011
Soil	AR	Diesel Range Organics (C10 - C24)	Determination of hexane/acetone extractable hydrocarbons by GC-FID	E004
Soil	AR	Electrical Conductivity	Determination of electrical conductivity by addition of saturated calcium sulphate followed by electrometric measurement	E022
Soil	AR	Electrical Conductivity	Determination of electrical conductivity by addition of water followed by electrometric measurement	E023
Soil	D	Elemental Sulphur	Determination of elemental sulphur by solvent extraction followed by GC-MS	E020
Soil	AR	EPH (C10 – C40)	Determination of acetone/hexane extractable hydrocarbons by GC-FID	E004
Soil	AR	EPH Product ID	Determination of acetone/hexane extractable hydrocarbons by GC-FID	E004
Soil	AR	EPH TEXAS	Determination of acetone/hexane extractable hydrocarbons by GC-FID	E004
Soil	D	Fluoride - Water Soluble	Determination of Fluoride by extraction with water & analysed by ion chromatography	E009
Soil	D	FOC (Fraction Organic Carbon)	Determination of fraction of organic carbon by oxidising with potassium dichromate followed by titration with iron (II) sulphate	E010
Soil	D	Loss on Ignition @ 450oC	Determination of loss on ignition in soil by gravimetrically with the sample being ignited in a muffle furnace	E019
Soil	D	Magnesium - Water Soluble	Determination of water soluble magnesium by extraction with water followed by ICP-OES	E025
Soil	D	Metals	Determination of metals by aqua-regia digestion followed by ICP-OES	E002
Soil	AR	Mineral Oil (C10 - C40)	Determination of hexane/acetone extractable hydrocarbons by GC-FID fractionating with SPE cartridge	E004
Soil	AR	Moisture Content	Moisture content; determined gravimetrically	E003
Soil	D	Nitrate - Water Soluble (2:1)	Determination of nitrate by extraction with water & analysed by ion chromatography	E009
Soil	D	Organic Matter	Determination of organic matter by oxidising with potassium dichromate followed by titration with iron (II) sulphate	E010
Soil	AR	PAH - Speciated (EPA 16)	Determination of PAH compounds by extraction in acetone and hexane followed by GC-MS with the use of surrogate and internal standards	E005
Soil	AR	PCB - 7 Congeners	Determination of PCB by extraction with acetone and hexane followed by GC-MS	E008
Soil	D	Petroleum Ether Extract (PEE)	Gravimetrically determined through extraction with petroleum ether	E011
Soil	AR	pH	Determination of pH by addition of water followed by electrometric measurement	E007
Soil	AR	Phenols - Total (monohydric)	Determination of phenols by distillation followed by colorimetry	E021
Soil	D	Phosphate - Water Soluble (2:1)	Determination of phosphate by extraction with water & analysed by ion chromatography	E009
Soil	D	Sulphate (as SO4) - Total	Determination of total sulphate by extraction with 10% HCl followed by ICP-OES	E013
Soil	D	Sulphate (as SO4) - Water Soluble (2:1)	Determination of sulphate by extraction with water & analysed by ion chromatography	E009
Soil	D	Sulphate (as SO4) - Water Soluble (2:1)	Determination of water soluble sulphate by extraction with water followed by ICP-OES	E014
Soil	AR	Sulphide	Determination of sulphide by distillation followed by colorimetry	E018
Soil	D	Sulphur - Total	Determination of total sulphur by extraction with aqua-regia followed by ICP-OES	E024
Soil	AR	SVOC	Determination of semi-volatile organic compounds by extraction in acetone and hexane followed by GC-MS	E006
Soil	AR	Thiocyanate (as SCN)	Determination of thiocyanate by extraction in caustic soda followed by acidification followed by addition of ferric nitrate followed by colorimetry	E017
Soil	D	Toluene Extractable Matter (TEM)	Gravimetrically determined through extraction with toluene	E011
Soil	D	Total Organic Carbon (TOC)	Determination of organic matter by oxidising with potassium dichromate followed by titration with iron (II) sulphate	E010
Soil	AR	TPH CWG	Determination of hexane/acetone extractable hydrocarbons by GC-FID fractionating with SPE cartridge	E004
Soil	AR	TPH LQM	Determination of hexane/acetone extractable hydrocarbons by GC-FID fractionating with SPE cartridge	E004
Soil	AR	VOCs	Determination of volatile organic compounds by headspace GC-MS	E001
Soil	AR	VPH (C6 - C10)	Determination of hydrocarbons C6-C10 by headspace GC-MS	E001

D Dried
AR As Received

John Bartley
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CO12 3HL

QTS Environmental Ltd
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Rose Lane Industrial Estate
Rose Lane
Lenham Heath
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ME17 2JN
t: 01622 850410
russell.jarvis@qtsenvironmental.com

QTS Environmental Report No: 14-25327

Site Reference:	Bedford Avenue
Project / Job Ref:	None Supplied
Order No:	None Supplied
Sample Receipt Date:	01/10/2014
Sample Scheduled Date:	02/10/2014
Report Issue Number:	1
Reporting Date:	08/10/2014

Authorised by:

Russell Jarvis
Director
On behalf of QTS Environmental Ltd

Authorised by:

Kevin Old
Director
On behalf of QTS Environmental Ltd

Soil Analysis Certificate

QTS Environmental Report No: 14-25327	**Date Sampled**	23/09/14	23/09/14			
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied			
Site Reference: Bedford Avenue	**TP / BH No**	BH2	BH2			
Project / Job Ref: None Supplied	**Additional Refs**	2/D	2/B			
Order No: None Supplied	**Depth (m)**	3.55	5.00 - 5.45			
Reporting Date: 08/10/2014	**QTSE Sample No**	120311	120312			

Determinand	**Unit**	**RL**	**Accreditation**					
Asbestos Screen	N/a	N/a	**ISO17025**	Not Detected	Not Detected			
pH	pH Units	N/a	**MCERTS**	7.7	8.6			
W/S Sulphate as SO4 (2:1)	g/l	< 0.01	**MCERTS**	0.18	0.36			
Elemental Sulphur	mg/kg	< 10	NONE	< 10	< 10			
Sulphide	mg/kg	< 5	NONE	< 5	< 5			
Total Organic Carbon (TOC)	%	< 0.1	NONE	0.3	0.5			
Arsenic (As)	mg/kg	< 2	**MCERTS**	6	14			
Beryllium (Be)	mg/kg	< 0.5	NONE	< 0.5	< 0.5			
W/S Boron	mg/kg	< 1	NONE	< 1	< 1			
Cadmium (Cd)	mg/kg	< 0.5	**MCERTS**	0.8	< 0.5			
Chromium (Cr)	mg/kg	< 2	**MCERTS**	12	11			
Chromium (hexavalent)	mg/kg	< 2	NONE	< 2	< 2			
Copper (Cu)	mg/kg	< 4	**MCERTS**	20	5			
Lead (Pb)	mg/kg	< 3	**MCERTS**	147	25			
Mercury (Hg)	mg/kg	< 1	NONE	< 1	< 1			
Nickel (Ni)	mg/kg	< 3	**MCERTS**	16	12			
Selenium (Se)	mg/kg	< 3	NONE	< 3	< 3			
Vanadium (V)	mg/kg	< 2	NONE	20	16			
Zinc (Zn)	mg/kg	< 3	**MCERTS**	199	42			
Total Phenols (monohydric)	mg/kg	< 2	NONE	< 2	< 2			

Analytical results are expressed on a dry weight basis where samples are dried at less than 30^{O}C

Analysis carried out on the dried sample is corrected for the stone content

The samples have been examined to identify the presence of asbestiform minerals by polarising light microscopy and dispersion staining technique to In-House Procedures QTSE600 Determination of Asbestos in Bulk Materials; Asbestos in Soils/Sediments (fibre screening and identification)

This report refers to samples as received, and QTS Environmental Ltd, takes no responsibility for the accuracy or competence of sampling by others.

The material description shall be regarded as tentative and is not included in our scope of UKAS Accreditation.

Opinions and interpretations expressed herein are outside the scope of UKAS Accreditation.

Asbestos Analyst: Graham Revell

RL: Reporting Limit

Pinch Test: Where pinch test is positive it is reported “Loose Fibres - PT” with type(s).

Subcontracted analysis $^{(S)}$

Soil Analysis Certificate - Speciated PAHs						
QTS Environmental Report No: 14-25327	**Date Sampled**	23/09/14	23/09/14			
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied			
Site Reference: Bedford Avenue	**TP / BH No**	BH2	BH2			
Project / Job Ref: None Supplied	**Additional Refs**	2/D	2/B			
Order No: None Supplied	**Depth (m)**	3.55	5.00 - 5.45			
Reporting Date: 08/10/2014	**QTSE Sample No**	120311	120312			

Determinand	**Unit**	**RL**	**Accreditation**					
Naphthalene	mg/kg	< 0.1	**MCERTS**	1.32	< 0.1			
Acenaphthylene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1			
Acenaphthene	mg/kg	< 0.1	**MCERTS**	1.71	< 0.1			
Fluorene	mg/kg	< 0.1	**MCERTS**	1.77	< 0.1			
Phenanthrene	mg/kg	< 0.1	**MCERTS**	11.70	< 0.1			
Anthracene	mg/kg	< 0.1	**MCERTS**	3.09	< 0.1			
Fluoranthene	mg/kg	< 0.1	**MCERTS**	9.35	< 0.1			
Pyrene	mg/kg	< 0.1	**MCERTS**	7.16	< 0.1			
Benzo(a)anthracene	mg/kg	< 0.1	**MCERTS**	3.64	< 0.1			
Chrysene	mg/kg	< 0.1	**MCERTS**	2.95	< 0.1			
Benzo(b)fluoranthene	mg/kg	< 0.1	**MCERTS**	2.60	< 0.1			
Benzo(k)fluoranthene	mg/kg	< 0.1	**MCERTS**	1.07	< 0.1			
Benzo(a)pyrene	mg/kg	< 0.1	**MCERTS**	2.18	< 0.1			
Indeno(1,2,3-cd)pyrene	mg/kg	< 0.1	**MCERTS**	0.87	< 0.1			
Dibenz(a,h)anthracene	mg/kg	< 0.1	**MCERTS**	0.13	< 0.1			
Benzo(ghi)perylene	mg/kg	< 0.1	**MCERTS**	0.67	< 0.1			
Coronene	mg/kg	< 0.1	NONE	0.40	< 0.1			
Total Oily Waste PAHs	mg/kg	< 1	**MCERTS**	13.4	< 1			
Total Dutch 10 PAHs	mg/kg	< 1	**MCERTS**	36.8	< 1			
Total EPA-16 PAHs	mg/kg	< 1.6	**MCERTS**	50.2	< 1.6			
Total WAC-17 PAHs	mg/kg	< 1.7	NONE	50.6	< 1.7			

Analytical results are expressed on a dry weight basis where samples are dried at less than 30^{O}C

Soil Analysis Certificate - EPH Oily Waste Banded

QTS Environmental Report No: 14-25327	**Date Sampled**	23/09/14	23/09/14			
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied			
Site Reference: Bedford Avenue	**TP / BH No**	BH2	BH2			
Project / Job Ref: None Supplied	**Additional Refs**	2/D	2/B			
Order No: None Supplied	**Depth (m)**	3.55	5.00 - 5.45			
Reporting Date: 08/10/2014	**QTSE Sample No**	120311	120312			

Determinand	**Unit**	**RL**	**Accreditation**					
Oily Waste (C6 - C10)	mg/kg	< 1	NONE	< 1	< 1			
Oily Waste (>C10 - C25)	mg/kg	< 1	**MCERTS**	70	< 1			
Oily Waste (>C25 - C40)	mg/kg	< 6	**MCERTS**	65	< 6			
Oily Waste (C6 - C40)	mg/kg	< 6	NONE	135	< 6			

Analytical results are expressed on a dry weight basis where samples are dried at less than 30^{O}C

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Soil Analysis Certificate - TPH CWG Banded

QTS Environmental Report No: 14-25327	**Date Sampled**	23/09/14	23/09/14			
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied			
Site Reference: Bedford Avenue	**TP / BH No**	BH2	BH2			
Project / Job Ref: None Supplied	**Additional Refs**	2/D	2/B			
Order No: None Supplied	**Depth (m)**	3.55	5.00 - 5.45			
Reporting Date: 08/10/2014	**QTSE Sample No**	120311	120312			

Determinand	**Unit**	**RL**	**Accreditation**					
Aliphatic >C5 - C6	mg/kg	< 0.01	NONE	< 0.01	< 0.01			
Aliphatic >C6 - C8	mg/kg	< 0.05	NONE	< 0.05	< 0.05			
Aliphatic >C8 - C10	mg/kg	< 1	NONE	< 1	< 1			
Aliphatic >C10 - C12	mg/kg	< 1	NONE	< 1	< 1			
Aliphatic >C12 - C16	mg/kg	< 1	NONE	< 1	< 1			
Aliphatic >C16 - C21	mg/kg	< 1	NONE	< 1	< 1			
Aliphatic >C21 - C34	mg/kg	< 6	NONE	28	< 6			
Aliphatic (C5 - C34)	mg/kg	< 12	NONE		< 12			
Aromatic >C5 - C7	mg/kg	< 0.01	NONE	< 0.01	< 0.01			
Aromatic >C7 - C8	mg/kg	< 0.05	NONE	< 0.05	< 0.05			
Aromatic >C8 - C10	mg/kg	< 1	NONE	< 1	< 1			
Aromatic >C10 - C12	mg/kg	< 1	NONE	2	< 1			
Aromatic >C12 - C16	mg/kg	< 1	NONE	10	< 1			
Aromatic >C16 - C21	mg/kg	< 1	NONE	26	< 1			
Aromatic >C21 - C35	mg/kg	< 6	NONE	44	< 6			
Aromatic (C5 - C35)	mg/kg	< 12	NONE	83	< 12			
Total >C5 - C35	mg/kg	< 24	NONE	121	< 24			

Analytical results are expressed on a dry weight basis where samples are dried at less than 30°C

Soil Analysis Certificate - BTEX / MTBE						
QTS Environmental Report No: 14-25327	**Date Sampled**	23/09/14	23/09/14			
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied			
Site Reference: Bedford Avenue	**TP / BH No**	BH2	BH2			
Project / Job Ref: None Supplied	**Additional Refs**	2/D	2/B			
Order No: None Supplied	**Depth (m)**	3.55	5.00 - 5.45			
Reporting Date: 08/10/2014	**QTSE Sample No**	120311	120312			

Determinand	**Unit**	**RL**	**Accreditation**					
Benzene	ug/kg	< 2	**MCERTS**	< 2	< 2			
Toluene	ug/kg	< 5	**MCERTS**	< 5	< 5			
Ethylbenzene	ug/kg	< 10	**MCERTS**	< 10	< 10			
p & m-xylene	ug/kg	< 10	**MCERTS**	< 10	< 10			
o-xylene	ug/kg	< 10	**MCERTS**	< 10	< 10			
MTBE	ug/kg	< 5	**MCERTS**	< 5	< 5			

Analytical results are expressed on a dry weight basis where samples are dried at less than 30^{O}C

Soil Analysis Certificate - Volatile Organic Compounds (VOC)

QTS Environmental Report No: 14-25327	**Date Sampled**	23/09/14	23/09/14			
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied			
Site Reference: Bedford Avenue	**TP / BH No**	BH2	BH2			
Project / Job Ref: None Supplied	**Additional Refs**	2/D	2/B			
Order No: None Supplied	**Depth (m)**	3.55	5.00 - 5.45			
Reporting Date: 08/10/2014	**QTSE Sample No**	120311	120312			

Determinand	**Unit**	**RL**	**Accreditation**					
Dichlorodifluoromethane	ug/kg	< 5	**MCERTS**	< 5	< 5			
Vinyl Chloride	ug/kg	< 5	**MCERTS**	< 5	< 5			
Chloromethane	ug/kg	< 10	**MCERTS**	< 10	< 10			
Chloroethane	ug/kg	< 5	**MCERTS**	< 5	< 5			
Bromomethane	ug/kg	< 10	**MCERTS**	< 10	< 10			
Trichlorofluoromethane	ug/kg	< 5	**MCERTS**	< 5	< 5			
1,1-Dichloroethene	ug/kg	< 5	**ISO17025**	< 5	< 5			
MTBE	ug/kg	< 5	**MCERTS**	< 5	< 5			
trans-1,2-Dichloroethene	ug/kg	< 5	**MCERTS**	< 5	< 5			
1,1-Dichloroethane	ug/kg	< 5	**MCERTS**	< 5	< 5			
cis-1,2-Dichloroethene	ug/kg	< 5	**MCERTS**	< 5	< 5			
2,2-Dichloropropane	ug/kg	< 5	**MCERTS**	< 5	< 5			
Chloroform	ug/kg	< 5	**MCERTS**	< 5	< 5			
Bromochloromethane	ug/kg	< 5	**MCERTS**	< 5	< 5			
1,1,1-Trichloroethane	ug/kg	< 5	**MCERTS**	< 5	< 5			
1,1-Dichloropropene	ug/kg	< 10	**MCERTS**	< 10	< 10			
Carbon Tetrachloride	ug/kg	< 5	**MCERTS**	< 5	< 5			
1,2-Dichloroethane	ug/kg	< 5	**MCERTS**	< 5	< 5			
Benzene	ug/kg	< 2	**MCERTS**	< 2	< 2			
1,2-Dichloropropane	ug/kg	< 5	**MCERTS**	< 5	< 5			
Trichloroethene	ug/kg	< 5	**MCERTS**	< 5	< 5			
Bromodichloromethane	ug/kg	< 5	**MCERTS**	< 5	< 5			
Dibromomethane	ug/kg	< 5	**MCERTS**	< 5	< 5			
TAME	ug/kg	< 5	**MCERTS**	< 5	< 5			
cis-1,3-Dichloropropene	ug/kg	< 5	**MCERTS**	< 5	< 5			
Toluene	ug/kg	< 5	**MCERTS**	< 5	< 5			
trans-1,3-Dichloropropene	ug/kg	< 5	**MCERTS**	< 5	< 5			
1,1,2-Trichloroethane	ug/kg	< 10	**MCERTS**	< 10	< 10			
1,3-Dichloropropane	ug/kg	< 5	**MCERTS**	< 5	< 5			
Tetrachloroethene	ug/kg	< 5	**MCERTS**	< 5	< 5			
Dibromochloromethane	ug/kg	< 5	**MCERTS**	< 5	< 5			
1,2-Dibromoethane	ug/kg	< 5	**MCERTS**	< 5	< 5			
Chlorobenzene	ug/kg	< 5	**MCERTS**	< 5	< 5			
1,1,1,2-Tetrachloroethane	ug/kg	< 5	**MCERTS**	< 5	< 5			
Ethyl Benzene	ug/kg	< 10	**MCERTS**	< 10	< 10			
m,p-Xylene	ug/kg	< 10	**MCERTS**	< 10	< 10			
o-Xylene	ug/kg	< 10	**MCERTS**	< 10	< 10			
Styrene	ug/kg	< 5	**MCERTS**	< 5	< 5			
Bromoform	ug/kg	< 10	**MCERTS**	< 10	< 10			
Isopropylbenzene	ug/kg	< 5	**MCERTS**	< 5	< 5			
1,1,2,2-Tetrachloroethane	ug/kg	< 5	**MCERTS**	< 5	< 5			
1,2,3-Trichloropropane	ug/kg	< 5	**MCERTS**	< 5	< 5			
n-Propylbenzene	ug/kg	< 5	**MCERTS**	< 5	< 5			
Bromobenzene	ug/kg	< 5	**MCERTS**	< 5	< 5			
2-Chlorotoluene	ug/kg	< 5	**MCERTS**	< 5	< 5			
1,3,5-Trimethylbenzene	ug/kg	< 5	**MCERTS**	< 5	< 5			
4-Chlorotoluene	ug/kg	< 5	**MCERTS**	< 5	< 5			
tert-Butylbenzene	ug/kg	< 5	**MCERTS**	< 5	< 5			
1,2,4-Trimethylbenzene	ug/kg	< 5	**MCERTS**	< 5	< 5			
sec-Butylbenzene	ug/kg	< 5	**MCERTS**	< 5	< 5			
p-Isopropyltoluene	ug/kg	< 5	**MCERTS**	< 5	< 5			
1,3-Dichlorobenzene	ug/kg	< 5	**MCERTS**	< 5	< 5			
1,4-Dichlorobenzene	ug/kg	< 5	**MCERTS**	< 5	< 5			
n-Butylbenzene	ug/kg	< 5	**MCERTS**	< 5	< 5			
1,2-Dichlorobenzene	ug/kg	< 5	**MCERTS**	< 5	< 5			
1,2-Dibromo-3-chloropropane	ug/kg	< 10	**MCERTS**	< 10	< 10			
Hexachlorobutadiene	ug/kg	< 5	**MCERTS**	< 5	< 5			

Analytical results are expressed on a dry weight basis where samples are dried at less than 30^{O}C

QTS Environmental Ltd
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Soil Analysis Certificate - Volatile Organic Compounds TIC (VOC)		
QTS Environmental Report No: 14-25327	**Date Sampled**	23/09/14
Soil Consultants Ltd	**Time Sampled**	None Supplied
Site Reference: Bedford Avenue	**TP / BH No**	BH2
Project / Job Ref: None Supplied	**Additional Refs**	2/D
Order No: None Supplied	**Depth (m)**	3.55
Reporting Date: 08/10/2014	**QTSE Sample No**	120311

Compound No	Compound Name	% Match	Units	RL	Estimated Concentration
1	N/a	N/a	µg/kg	< 10	< 10
2	N/a	N/a	µg/kg	< 10	< 10
3	N/a	N/a	µg/kg	< 10	< 10
4	N/a	N/a	µg/kg	< 10	< 10
5	N/a	N/a	µg/kg	< 10	< 10

There were no / other compounds identified with a match of >90%

Soil Analysis Certificate - Volatile Organic Compounds TIC (VOC)		
QTS Environmental Report No: 14-25327	**Date Sampled**	23/09/14
Soil Consultants Ltd	**Time Sampled**	None Supplied
Site Reference: Bedford Avenue	**TP / BH No**	BH2
Project / Job Ref: None Supplied	**Additional Refs**	2/B
Order No: None Supplied	**Depth (m)**	5.00 - 5.45
Reporting Date: 08/10/2014	**QTSE Sample No**	120312

Compound No	Compound Name	% Match	Units	RL	Estimated Concentration
1	N/a	N/a	µg/kg	< 10	< 10
2	N/a	N/a	µg/kg	< 10	< 10
3	N/a	N/a	µg/kg	< 10	< 10
4	N/a	N/a	µg/kg	< 10	< 10
5	N/a	N/a	µg/kg	< 10	< 10

There were no / other compounds identified with a match of >90%

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Soil Analysis Certificate - Semi Volatile Organic Compounds (SVOC)						
QTS Environmental Report No: 14-25327	**Date Sampled**	23/09/14	23/09/14			
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied			
Site Reference: Bedford Avenue	**TP / BH No**	BH2	BH2			
Project / Job Ref: None Supplied	**Additional Refs**	2/D	2/B			
Order No: None Supplied	**Depth (m)**	3.55	5.00 - 5.45			
Reporting Date: 08/10/2014	**QTSE Sample No**	120311	120312			

Determinand	**Unit**	**RL**	**Accreditation**					
Phenol	mg/kg	< 0.1	NONE	< 0.1	< 0.1			
1,2,4-Trichlorobenzene	mg/kg	< 0.1	**ISO17025**	< 0.1	< 0.1			
2-Nitrophenol	mg/kg	< 0.1	NONE	< 0.1	< 0.1			
Nitrobenzene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1			
0-Cresol	mg/kg	< 0.1	NONE	< 0.1	< 0.1			
bis(2-chloroethoxy)methane	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1			
bis(2-chloroethyl)ether	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1			
2,4-Dichlorophenol	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1			
2-Chlorophenol	mg/kg	< 0.1	**ISO17025**	< 0.1	< 0.1			
1,3-Dichlorobenzene	mg/kg	< 0.1	**ISO17025**	< 0.1	< 0.1			
1,4-Dichlorobenzene	mg/kg	< 0.1	**ISO17025**	< 0.1	< 0.1			
1,2-Dichlorobenzene	mg/kg	< 0.1	**ISO17025**	< 0.1	< 0.1			
2,4-Dimethylphenol	mg/kg	< 0.15	**ISO17025**	< 0.15	< 0.15			
Isophorone	mg/kg	< 0.1	NONE	< 0.1	< 0.1			
Hexachloroethane	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1			
p-Cresol	mg/kg	< 0.15	**MCERTS**	< 0.15	< 0.15			
2,4,6-Trichlorophenol	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1			
2,4,5-Trichlorophenol	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1			
2-Nitroaniline	mg/kg	< 0.1	NONE	< 0.1	< 0.1			
4-Chloro-3-methylphenol	mg/kg	< 0.1	NONE	< 0.1	< 0.1			
2-Methylnaphthalene	mg/kg	< 0.1	**MCERTS**	0.2	< 0.1			
Hexachlorocyclopentadiene	mg/kg	< 0.1	NONE	< 0.1	< 0.1			
Hexachlorobutadiene	mg/kg	< 0.1	**ISO17025**	< 0.1	< 0.1			
2,6-Dinitrotoluene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1			
Dimethyl phthalate	mg/kg	< 0.1	NONE	< 0.1	< 0.1			
2-Chloronaphthalene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1			
4-Chloroanaline	mg/kg	< 0.2	NONE	< 0.2	< 0.2			
4-Nitrophenol	mg/kg	< 0.1	NONE	< 0.1	< 0.1			
4-Chlorophenyl phenyl ether	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1			
3-Nitroaniline	mg/kg	< 0.1	NONE	< 0.1	< 0.1			
4-Nitroaniline	mg/kg	< 0.1	NONE	< 0.1	< 0.1			
4-Bromophenyl phenyl ether	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1			
Hexachlorobenzene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1			
2,4-Dinitrotoluene	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1			
Diethyl phthalate	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1			
Dibenzofuran	mg/kg	< 0.1	**MCERTS**	0.5	< 0.1			
Azobenzene	mg/kg	< 0.1	NONE	< 0.1	< 0.1			
Dibutyl phthalate	mg/kg	< 0.15	**ISO17025**	< 0.15	< 0.15			
Carbazole	mg/kg	< 0.1	**ISO17025**	0.7	< 0.1			
bis(2-ethylhexyl)phthalate	mg/kg	< 0.2	**MCERTS**	0.2	< 0.2			
Benzyl butyl phthalate	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1			
Di-n-octyl phthalate	mg/kg	< 0.1	**MCERTS**	< 0.1	< 0.1			

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Soil Analysis Certificate - Semi Volatile Organic Compounds TIC (SVOC)		
QTS Environmental Report No: 14-25327	**Date Sampled**	23/09/14
Soil Consultants Ltd	**Time Sampled**	None Supplied
Site Reference: Bedford Avenue	**TP / BH No**	BH2
Project / Job Ref: None Supplied	**Additional Refs**	2/D
Order No: None Supplied	**Depth (m)**	3.55
Reporting Date: 08/10/2014	**QTSE Sample No**	120311

Compound No	**Compound Name**	**% Match**	**Units**	**RL**	**Estimated Concentration**
1	N/a	N/a	mg/kg	< 0.1	< 0.1
2	N/a	N/a	mg/kg	< 0.1	< 0.1
3	N/a	N/a	mg/kg	< 0.1	< 0.1
4	N/a	N/a	mg/kg	< 0.1	< 0.1
5	N/a	N/a	mg/kg	< 0.1	< 0.1

There were no / other compounds identified with a match of >90%

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Soil Analysis Certificate - Semi Volatile Organic Compounds TIC (SVOC)		
QTS Environmental Report No: 14-25327	**Date Sampled**	23/09/14
Soil Consultants Ltd	**Time Sampled**	None Supplied
Site Reference: Bedford Avenue	**TP / BH No**	BH2
Project / Job Ref: None Supplied	**Additional Refs**	2/B
Order No: None Supplied	**Depth (m)**	5.00 - 5.45
Reporting Date: 08/10/2014	**QTSE Sample No**	120312

Compound No	**Compound Name**	**% Match**	**Units**	**RL**	**Estimated Concentration**
1	N/a	N/a	mg/kg	< 0.1	< 0.1
2	N/a	N/a	mg/kg	< 0.1	< 0.1
3	N/a	N/a	mg/kg	< 0.1	< 0.1
4	N/a	N/a	mg/kg	< 0.1	< 0.1
5	N/a	N/a	mg/kg	< 0.1	< 0.1

There were no / other compounds identified with a match of >90%

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Soil Analysis Certificate - PCB (7 Congeners)						
QTS Environmental Report No: 14-25327	**Date Sampled**	23/09/14	23/09/14			
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied			
Site Reference: Bedford Avenue	**TP / BH No**	BH2	BH2			
Project / Job Ref: None Supplied	**Additional Refs**	2/D	2/B			
Order No: None Supplied	**Depth (m)**	3.55	5.00 - 5.45			
Reporting Date: 08/10/2014	**QTSE Sample No**	120311	120312			

Determinand	**Unit**	**RL**	**Accreditation**					
PCB Congener 28	mg/kg	< 0.008	NONE	< 0.008	< 0.008			
PCB Congener 52	mg/kg	< 0.008	NONE	< 0.008	< 0.008			
PCB Congener 101	mg/kg	< 0.008	NONE	< 0.008	< 0.008			
PCB Congener 118	mg/kg	< 0.008	NONE	< 0.008	< 0.008			
PCB Congener 138	mg/kg	< 0.008	NONE	< 0.008	< 0.008			
PCB Congener 153	mg/kg	< 0.008	NONE	< 0.008	< 0.008			
PCB Congener 180	mg/kg	< 0.008	NONE	< 0.008	< 0.008			
Total PCB (7 Congeners)	mg/kg	< 0.1	NONE	< 0.1	< 0.1			

Analytical results are expressed on a dry weight basis where samples are dried at less than 30^{O}C

Soil Analysis Certificate - Sample Descriptions

QTS Environmental Report No: 14-25327
Soil Consultants Ltd
Site Reference: Bedford Avenue
Project / Job Ref: None Supplied
Order No: None Supplied
Reporting Date: 08/10/2014

QTSE Sample No	TP / BH No	Additional Refs	Depth (m)	Moisture Content (%)	Sample Matrix Description
120311	BH2	2/D	3.55	6.8	Brown clayey gravel with stones
120312	BH2	2/B	5.00 - 5.45	5.2	Brown sandy gravel with stones

Moisture content is part of procedure E003 & is not an accredited test
Insufficient Sample $^{I/S}$
Unsuitable Sample $^{U/S}$

Soil Analysis Certificate - Methodology & Miscellaneous Information
QTS Environmental Report No: 14-25327
Soil Consultants Ltd
Site Reference: Bedford Avenue
Project / Job Ref: None Supplied
Order No: None Supplied
Reporting Date: 08/10/2014

Matrix	Analysed On	Determinand	Brief Method Description	Method No
Soil	D	Boron - Water Soluble	Determination of water soluble boron in soil by 2:1 hot water extract followed by ICP-OES	E012
Soil	AR	BTEX	Determination of BTEX by headspace GC-MS	E001
Soil	D	Cations	Determination of cations in soil by aqua-regia digestion followed by ICP-OES	E002
Soil	D	Chloride - Water Soluble (2:1)	Determination of chloride by extraction with water & analysed by ion chromatography	E009
Soil	AR	Chromium - Hexavalent	Determination of hexavalent chromium in soil by extraction in water then by acidification, addition of 1,5 diphenylcarbazide followed by colorimetry	E016
Soil	AR	Cyanide - Complex	Determination of complex cyanide by distillation followed by colorimetry	E015
Soil	AR	Cyanide - Free	Determination of free cyanide by distillation followed by colorimetry	E015
Soil	AR	Cyanide - Total	Determination of total cyanide by distillation followed by colorimetry	E015
Soil	D	Cyclohexane Extractable Matter (CEM)	Gravimetrically determined through extraction with cyclohexane	E011
Soil	AR	Diesel Range Organics (C10 - C24)	Determination of hexane/acetone extractable hydrocarbons by GC-FID	E004
Soil	AR	Electrical Conductivity	Determination of electrical conductivity by addition of saturated calcium sulphate followed by electrometric measurement	E022
Soil	AR	Electrical Conductivity	Determination of electrical conductivity by addition of water followed by electrometric measurement	E023
Soil	D	Elemental Sulphur	Determination of elemental sulphur by solvent extraction followed by GC-MS	E020
Soil	AR	EPH (C10 – C40)	Determination of acetone/hexane extractable hydrocarbons by GC-FID	E004
Soil	AR	EPH Product ID	Determination of acetone/hexane extractable hydrocarbons by GC-FID	E004
Soil	AR	EPH TEXAS	Determination of acetone/hexane extractable hydrocarbons by GC-FID	E004
Soil	D	Fluoride - Water Soluble	Determination of Fluoride by extraction with water & analysed by ion chromatography	E009
Soil	D	FOC (Fraction Organic Carbon)	Determination of fraction of organic carbon by oxidising with potassium dichromate followed by titration with iron (II) sulphate	E010
Soil	D	Loss on Ignition @ 450oC	Determination of loss on ignition in soil by gravimetrically with the sample being ignited in a muffle furnace	E019
Soil	D	Magnesium - Water Soluble	Determination of water soluble magnesium by extraction with water followed by ICP-OES	E025
Soil	D	Metals	Determination of metals by aqua-regia digestion followed by ICP-OES	E002
Soil	AR	Mineral Oil (C10 - C40)	Determination of hexane/acetone extractable hydrocarbons by GC-FID fractionating with SPE cartridge	E004
Soil	AR	Moisture Content	Moisture content; determined gravimetrically	E003
Soil	D	Nitrate - Water Soluble (2:1)	Determination of nitrate by extraction with water & analysed by ion chromatography	E009
Soil	D	Organic Matter	Determination of organic matter by oxidising with potassium dichromate followed by titration with iron (II) sulphate	E010
Soil	AR	PAH - Speciated (EPA 16)	Determination of PAH compounds by extraction in acetone and hexane followed by GC-MS with the use of surrogate and internal standards	E005
Soil	AR	PCB - 7 Congeners	Determination of PCB by extraction with acetone and hexane followed by GC-MS	E008
Soil	D	Petroleum Ether Extract (PEE)	Gravimetrically determined through extraction with petroleum ether	E011
Soil	AR	pH	Determination of pH by addition of water followed by electrometric measurement	E007
Soil	AR	Phenols - Total (monohydric)	Determination of phenols by distillation followed by colorimetry	E021
Soil	D	Phosphate - Water Soluble (2:1)	Determination of phosphate by extraction with water & analysed by ion chromatography	E009
Soil	D	Sulphate (as SO4) - Total	Determination of total sulphate by extraction with 10% HCl followed by ICP-OES	E013
Soil	D	Sulphate (as SO4) - Water Soluble (2:1)	Determination of sulphate by extraction with water & analysed by ion chromatography	E009
Soil	D	Sulphate (as SO4) - Water Soluble (2:1)	Determination of water soluble sulphate by extraction with water followed by ICP-OES	E014
Soil	AR	Sulphide	Determination of sulphide by distillation followed by colorimetry	E018
Soil	D	Sulphur - Total	Determination of total sulphur by extraction with aqua-regia followed by ICP-OES	E024
Soil	AR	SVOC	Determination of semi-volatile organic compounds by extraction in acetone and hexane followed by GC-MS	E006
Soil	AR	Thiocyanate (as SCN)	Determination of thiocyanate by extraction in caustic soda followed by acidification followed by addition of ferric nitrate followed by colorimetry	E017
Soil	D	Toluene Extractable Matter (TEM)	Gravimetrically determined through extraction with toluene	E011
Soil	D	Total Organic Carbon (TOC)	Determination of organic matter by oxidising with potassium dichromate followed by titration with iron (II) sulphate	E010
Soil	AR	TPH CWG	Determination of hexane/acetone extractable hydrocarbons by GC-FID fractionating with SPE cartridge	E004
Soil	AR	TPH LQM	Determination of hexane/acetone extractable hydrocarbons by GC-FID fractionating with SPE cartridge	E004
Soil	AR	VOCs	Determination of volatile organic compounds by headspace GC-MS	E001
Soil	AR	VPH (C6 - C10)	Determination of hydrocarbons C6-C10 by headspace GC-MS	E001

D	**Dried**
AR	**As Received**

John Bartley
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QTS Environmental Report No: 14-25397

Site Reference: Bedford Avenue

Project / Job Ref: None Supplied

Order No: None Supplied

Sample Receipt Date: 03/10/2014

Sample Scheduled Date: 06/10/2014

Report Issue Number: 2

Reporting Date: 05/11/2014

Authorised by:

Russell Jarvis
Director
On behalf of QTS Environmental Ltd

Authorised by:

Kevin Old
Director
On behalf of QTS Environmental Ltd

Soil Analysis Certificate						
QTS Environmental Report No: 14-25397	**Date Sampled**	None Supplied				
Soil Consultants Ltd	**Time Sampled**	None Supplied				
Site Reference: Bedford Avenue	**TP / BH No**	TP12				
Project / Job Ref: None Supplied	**Additional Refs**	None Supplied				
Order No: None Supplied	**Depth (m)**	0.65				
Reporting Date: 05/11/2014	**QTSE Sample No**	120671				

Determinand	**Unit**	**RL**	**Accreditation**				
Asbestos Screen	N/a	N/a	**ISO17025**	Not Detected			
pH	pH Units	N/a	**MCERTS**	8.2			
W/S Sulphate as SO4 (2:1)	g/l	< 0.01	**MCERTS**	0.08			
Elemental Sulphur	mg/kg	< 10	NONE	< 10			
Sulphide	mg/kg	< 5	NONE	< 5			
Total Organic Carbon (TOC)	%	< 0.1	NONE	0.3			
Arsenic (As)	mg/kg	< 2	**MCERTS**	5			
Beryllium (Be)	mg/kg	< 0.5	NONE	< 0.5			
W/S Boron	mg/kg	< 1	NONE	< 1			
Cadmium (Cd)	mg/kg	< 0.5	**MCERTS**	< 0.5			
Chromium (Cr)	mg/kg	< 2	**MCERTS**	16			
Chromium (hexavalent)	mg/kg	< 2	NONE	< 2			
Copper (Cu)	mg/kg	< 4	**MCERTS**	20			
Lead (Pb)	mg/kg	< 3	**MCERTS**	13			
Mercury (Hg)	mg/kg	< 1	NONE	< 1			
Nickel (Ni)	mg/kg	< 3	**MCERTS**	16			
Selenium (Se)	mg/kg	< 3	NONE	< 3			
Vanadium (V)	mg/kg	< 2	NONE	23			
Zinc (Zn)	mg/kg	< 3	**MCERTS**	38			
Total Phenols (monohydric)	mg/kg	< 2	NONE	< 2			

Analytical results are expressed on a dry weight basis where samples are dried at less than 30^{O}C

Analysis carried out on the dried sample is corrected for the stone content

The samples have been examined to identify the presence of asbestiform minerals by polarising light microscopy and dispersion staining technique to In-House Procedures QTSE600 Determination of Asbestos in Bulk Materials; Asbestos in Soils/Sediments (fibre screening and identification)

This report refers to samples as received, and QTS Environmental Ltd, takes no responsibility for the accuracy or competence of sampling by others.

The material description shall be regarded as tentative and is not included in our scope of UKAS Accreditation.

Opinions and interpretations expressed herein are outside the scope of UKAS Accreditation.

Asbestos Analyst: Javeed Malik

RL: Reporting Limit

Pinch Test: Where pinch test is positive it is reported “Loose Fibres - PT” with type(s).

Subcontracted analysis $^{(S)}$

Soil Analysis Certificate - Speciated PAHs						
QTS Environmental Report No: 14-25397	**Date Sampled**	None Supplied				
Soil Consultants Ltd	**Time Sampled**	None Supplied				
Site Reference: Bedford Avenue	**TP / BH No**	TP12				
Project / Job Ref: None Supplied	**Additional Refs**	None Supplied				
Order No: None Supplied	**Depth (m)**	0.65				
Reporting Date: 05/11/2014	**QTSE Sample No**	120671				

Determinand	**Unit**	**RL**	**Accreditation**					
Naphthalene	mg/kg	< 0.1	**MCERTS**	< 0.1				
Acenaphthylene	mg/kg	< 0.1	**MCERTS**	< 0.1				
Acenaphthene	mg/kg	< 0.1	**MCERTS**	< 0.1				
Fluorene	mg/kg	< 0.1	**MCERTS**	< 0.1				
Phenanthrene	mg/kg	< 0.1	**MCERTS**	< 0.1				
Anthracene	mg/kg	< 0.1	**MCERTS**	< 0.1				
Fluoranthene	mg/kg	< 0.1	**MCERTS**	< 0.1				
Pyrene	mg/kg	< 0.1	**MCERTS**	< 0.1				
Benzo(a)anthracene	mg/kg	< 0.1	**MCERTS**	< 0.1				
Chrysene	mg/kg	< 0.1	**MCERTS**	< 0.1				
Benzo(b)fluoranthene	mg/kg	< 0.1	**MCERTS**	< 0.1				
Benzo(k)fluoranthene	mg/kg	< 0.1	**MCERTS**	< 0.1				
Benzo(a)pyrene	mg/kg	< 0.1	**MCERTS**	< 0.1				
Indeno(1,2,3-cd)pyrene	mg/kg	< 0.1	**MCERTS**	< 0.1				
Dibenz(a,h)anthracene	mg/kg	< 0.1	**MCERTS**	< 0.1				
Benzo(ghi)perylene	mg/kg	< 0.1	**MCERTS**	< 0.1				
Coronene	mg/kg	< 0.1	NONE	< 0.1				
Total Oily Waste PAHs	mg/kg	< 1	**MCERTS**	< 1				
Total Dutch 10 PAHs	mg/kg	< 1	**MCERTS**	< 1				
Total EPA-16 PAHs	mg/kg	< 1.6	**MCERTS**	< 1.6				
Total WAC-17 PAHs	mg/kg	< 1.7	NONE	< 1.7				

Analytical results are expressed on a dry weight basis where samples are dried at less than 30^{O}C

Soil Analysis Certificate - EPH Oily Waste Banded

QTS Environmental Report No: 14-25397	**Date Sampled**	None Supplied				
Soil Consultants Ltd	**Time Sampled**	None Supplied				
Site Reference: Bedford Avenue	**TP / BH No**	TP12				
Project / Job Ref: None Supplied	**Additional Refs**	None Supplied				
Order No: None Supplied	**Depth (m)**	0.65				
Reporting Date: 05/11/2014	**QTSE Sample No**	120671				

Determinand	**Unit**	**RL**	**Accreditation**					
Oily Waste (C6 - C10)	mg/kg	< 1	NONE	< 1				
Oily Waste (>C10 - C25)	mg/kg	< 1	**MCERTS**	< 1				
Oily Waste (>C25 - C40)	mg/kg	< 6	**MCERTS**	< 6				
Oily Waste (C6 - C40)	mg/kg	< 6	NONE	< 6				

Analytical results are expressed on a dry weight basis where samples are dried at less than 30°C

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Soil Analysis Certificate - TPH CWG Banded						
QTS Environmental Report No: 14-25397	**Date Sampled**	None Supplied				
Soil Consultants Ltd	**Time Sampled**	None Supplied				
Site Reference: Bedford Avenue	**TP / BH No**	TP12				
Project / Job Ref: None Supplied	**Additional Refs**	None Supplied				
Order No: None Supplied	**Depth (m)**	0.65				
Reporting Date: 05/11/2014	**QTSE Sample No**	120671				

Determinand	**Unit**	**RL**	**Accreditation**					
Aliphatic >C5 - C6	mg/kg	< 0.01	NONE	< 0.01				
Aliphatic >C6 - C8	mg/kg	< 0.05	NONE	< 0.05				
Aliphatic >C8 - C10	mg/kg	< 1	NONE	< 1				
Aliphatic >C10 - C12	mg/kg	< 1	NONE	< 1				
Aliphatic >C12 - C16	mg/kg	< 1	NONE	< 1				
Aliphatic >C16 - C21	mg/kg	< 1	NONE	< 1				
Aliphatic >C21 - C34	mg/kg	< 6	NONE	< 6				
Aliphatic (C5 - C34)	mg/kg	< 12	NONE	< 12				
Aromatic >C5 - C7	mg/kg	< 0.01	NONE	< 0.01				
Aromatic >C7 - C8	mg/kg	< 0.05	NONE	< 0.05				
Aromatic >C8 - C10	mg/kg	< 1	NONE	< 1				
Aromatic >C10 - C12	mg/kg	< 1	NONE	< 1				
Aromatic >C12 - C16	mg/kg	< 1	NONE	< 1				
Aromatic >C16 - C21	mg/kg	< 1	NONE	< 1				
Aromatic >C21 - C35	mg/kg	< 6	NONE	< 6				
Aromatic (C5 - C35)	mg/kg	< 12	NONE	< 12				
Total >C5 - C35	mg/kg	< 24	NONE	< 24				

Analytical results are expressed on a dry weight basis where samples are dried at less than 30^{O}C

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UKAS TESTING 4480

Soil Analysis Certificate - BTEX / MTBE

QTS Environmental Report No: 14-25397	**Date Sampled**	None Supplied				
Soil Consultants Ltd	**Time Sampled**	None Supplied				
Site Reference: Bedford Avenue	**TP / BH No**	TP12				
Project / Job Ref: None Supplied	**Additional Refs**	None Supplied				
Order No: None Supplied	**Depth (m)**	0.65				
Reporting Date: 05/11/2014	**QTSE Sample No**	120671				

Determinand	**Unit**	**RL**	**Accreditation**					
Benzene	ug/kg	< 2	**MCERTS**	< 2				
Toluene	ug/kg	< 5	**MCERTS**	< 5				
Ethylbenzene	ug/kg	< 10	**MCERTS**	< 10				
p & m-xylene	ug/kg	< 10	**MCERTS**	< 10				
o-xylene	ug/kg	< 10	**MCERTS**	< 10				
MTBE	ug/kg	< 5	**MCERTS**	< 5				

Analytical results are expressed on a dry weight basis where samples are dried at less than 30°C

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Soil Analysis Certificate - Volatile Organic Compounds (VOC)

QTS Environmental Report No: 14-25397	**Date Sampled**	None Supplied				
Soil Consultants Ltd	**Time Sampled**	None Supplied				
Site Reference: Bedford Avenue	**TP / BH No**	TP12				
Project / Job Ref: None Supplied	**Additional Refs**	None Supplied				
Order No: None Supplied	**Depth (m)**	0.65				
Reporting Date: 05/11/2014	**QTSE Sample No**	120671				

Determinand	**Unit**	**RL**	**Accreditation**					
Dichlorodifluoromethane	ug/kg	< 5	**MCERTS**	< 5				
Vinyl Chloride	ug/kg	< 5	**MCERTS**	< 5				
Chloromethane	ug/kg	< 10	**MCERTS**	< 10				
Chloroethane	ug/kg	< 5	**MCERTS**	< 5				
Bromomethane	ug/kg	< 10	**MCERTS**	< 10				
Trichlorofluoromethane	ug/kg	< 5	**MCERTS**	< 5				
1,1-Dichloroethene	ug/kg	< 5	**ISO17025**	< 5				
MTBE	ug/kg	< 5	**MCERTS**	< 5				
trans-1,2-Dichloroethene	ug/kg	< 5	**MCERTS**	< 5				
1,1-Dichloroethane	ug/kg	< 5	**MCERTS**	< 5				
cis-1,2-Dichloroethene	ug/kg	< 5	**MCERTS**	< 5				
2,2-Dichloropropane	ug/kg	< 5	**MCERTS**	< 5				
Chloroform	ug/kg	< 5	**MCERTS**	< 5				
Bromochloromethane	ug/kg	< 5	**MCERTS**	< 5				
1,1,1-Trichloroethane	ug/kg	< 5	**MCERTS**	< 5				
1,1-Dichloropropene	ug/kg	< 10	**MCERTS**	< 10				
Carbon Tetrachloride	ug/kg	< 5	**MCERTS**	< 5				
1,2-Dichloroethane	ug/kg	< 5	**MCERTS**	< 5				
Benzene	ug/kg	< 2	**MCERTS**	< 2				
1,2-Dichloropropane	ug/kg	< 5	**MCERTS**	< 5				
Trichloroethene	ug/kg	< 5	**MCERTS**	< 5				
Bromodichloromethane	ug/kg	< 5	**MCERTS**	< 5				
Dibromomethane	ug/kg	< 5	**MCERTS**	< 5				
TAME	ug/kg	< 5	**MCERTS**	< 5				
cis-1,3-Dichloropropene	ug/kg	< 5	**MCERTS**	< 5				
Toluene	ug/kg	< 5	**MCERTS**	< 5				
trans-1,3-Dichloropropene	ug/kg	< 5	**MCERTS**	< 5				
1,1,2-Trichloroethane	ug/kg	< 10	**MCERTS**	< 10				
1,3-Dichloropropane	ug/kg	< 5	**MCERTS**	< 5				
Tetrachloroethene	ug/kg	< 5	**MCERTS**	< 5				
Dibromochloromethane	ug/kg	< 5	**MCERTS**	< 5				
1,2-Dibromoethane	ug/kg	< 5	**MCERTS**	< 5				
Chlorobenzene	ug/kg	< 5	**MCERTS**	< 5				
1,1,1,2-Tetrachloroethane	ug/kg	< 5	**MCERTS**	< 5				
Ethyl Benzene	ug/kg	< 10	**MCERTS**	< 10				
m,p-Xylene	ug/kg	< 10	**MCERTS**	< 10				
o-Xylene	ug/kg	< 10	**MCERTS**	< 10				
Styrene	ug/kg	< 5	**MCERTS**	< 5				
Bromoform	ug/kg	< 10	**MCERTS**	< 10				
Isopropylbenzene	ug/kg	< 5	**MCERTS**	< 5				
1,1,2,2-Tetrachloroethane	ug/kg	< 5	**MCERTS**	< 5				
1,2,3-Trichloropropane	ug/kg	< 5	**MCERTS**	< 5				
n-Propylbenzene	ug/kg	< 5	**MCERTS**	< 5				
Bromobenzene	ug/kg	< 5	**MCERTS**	< 5				
2-Chlorotoluene	ug/kg	< 5	**MCERTS**	< 5				
1,3,5-Trimethylbenzene	ug/kg	< 5	**MCERTS**	< 5				
4-Chlorotoluene	ug/kg	< 5	**MCERTS**	< 5				
tert-Butylbenzene	ug/kg	< 5	**MCERTS**	< 5				
1,2,4-Trimethylbenzene	ug/kg	< 5	**MCERTS**	< 5				
sec-Butylbenzene	ug/kg	< 5	**MCERTS**	< 5				
p-Isopropyltoluene	ug/kg	< 5	**MCERTS**	< 5				
1,3-Dichlorobenzene	ug/kg	< 5	**MCERTS**	< 5				
1,4-Dichlorobenzene	ug/kg	< 5	**MCERTS**	< 5				
n-Butylbenzene	ug/kg	< 5	**MCERTS**	< 5				
1,2-Dichlorobenzene	ug/kg	< 5	**MCERTS**	< 5				
1,2-Dibromo-3-chloropropane	ug/kg	< 10	**MCERTS**	< 10				
Hexachlorobutadiene	ug/kg	< 5	**MCERTS**	< 5				

Analytical results are expressed on a dry weight basis where samples are dried at less than 30^{O}C

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Soil Analysis Certificate - Volatile Organic Compounds TIC (VOC)		
QTS Environmental Report No: 14-25397	**Date Sampled**	None Supplied
Soil Consultants Ltd	**Time Sampled**	None Supplied
Site Reference: Bedford Avenue	**TP / BH No**	TP12
Project / Job Ref: None Supplied	**Additional Refs**	None Supplied
Order No: None Supplied	**Depth (m)**	0.65
Reporting Date: 05/11/2014	**QTSE Sample No**	120671

Compound No	Compound Name	% Match	Units	RL	Estimated Concentration
1	N/a	N/a	µg/kg	< 10	< 10
2	N/a	N/a	µg/kg	< 10	< 10
3	N/a	N/a	µg/kg	< 10	< 10
4	N/a	N/a	µg/kg	< 10	< 10
5	N/a	N/a	µg/kg	< 10	< 10

There were no / other compounds identified with a match of >90%

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Soil Analysis Certificate - Semi Volatile Organic Compounds (SVOC)

QTS Environmental Report No: 14-25397	**Date Sampled**	None Supplied				
Soil Consultants Ltd	**Time Sampled**	None Supplied				
Site Reference: Bedford Avenue	**TP / BH No**	TP12				
Project / Job Ref: None Supplied	**Additional Refs**	None Supplied				
Order No: None Supplied	**Depth (m)**	0.65				
Reporting Date: 05/11/2014	**QTSE Sample No**	120671				

Determinand	**Unit**	**RL**	**Accreditation**				
Phenol	mg/kg	< 0.1	NONE	< 0.1			
1,2,4-Trichlorobenzene	mg/kg	< 0.1	**ISO17025**	< 0.1			
2-Nitrophenol	mg/kg	< 0.1	NONE	< 0.1			
Nitrobenzene	mg/kg	< 0.1	**MCERTS**	< 0.1			
0-Cresol	mg/kg	< 0.1	NONE	< 0.1			
bis(2-chloroethoxy)methane	mg/kg	< 0.1	**MCERTS**	< 0.1			
bis(2-chloroethyl)ether	mg/kg	< 0.1	**MCERTS**	< 0.1			
2,4-Dichlorophenol	mg/kg	< 0.1	**MCERTS**	< 0.1			
2-Chlorophenol	mg/kg	< 0.1	**ISO17025**	< 0.1			
1,3-Dichlorobenzene	mg/kg	< 0.1	**ISO17025**	< 0.1			
1,4-Dichlorobenzene	mg/kg	< 0.1	**ISO17025**	< 0.1			
1,2-Dichlorobenzene	mg/kg	< 0.1	**ISO17025**	< 0.1			
2,4-Dimethylphenol	mg/kg	< 0.15	**ISO17025**	< 0.15			
Isophorone	mg/kg	< 0.1	NONE	< 0.1			
Hexachloroethane	mg/kg	< 0.1	**MCERTS**	< 0.1			
p-Cresol	mg/kg	< 0.15	**MCERTS**	< 0.15			
2,4,6-Trichlorophenol	mg/kg	< 0.1	**MCERTS**	< 0.1			
2,4,5-Trichlorophenol	mg/kg	< 0.1	**MCERTS**	< 0.1			
2-Nitroaniline	mg/kg	< 0.1	NONE	< 0.1			
4-Chloro-3-methylphenol	mg/kg	< 0.1	NONE	< 0.1			
2-Methylnaphthalene	mg/kg	< 0.1	**MCERTS**	< 0.1			
Hexachlorocyclopentadiene	mg/kg	< 0.1	NONE	< 0.1			
Hexachlorobutadiene	mg/kg	< 0.1	**ISO17025**	< 0.1			
2,6-Dinitrotoluene	mg/kg	< 0.1	**MCERTS**	< 0.1			
Dimethyl phthalate	mg/kg	< 0.1	NONE	< 0.1			
2-Chloronaphthalene	mg/kg	< 0.1	**MCERTS**	< 0.1			
4-Chloroanaline	mg/kg	< 0.2	NONE	< 0.2			
4-Nitrophenol	mg/kg	< 0.1	NONE	< 0.1			
4-Chlorophenyl phenyl ether	mg/kg	< 0.1	**MCERTS**	< 0.1			
3-Nitroaniline	mg/kg	< 0.1	NONE	< 0.1			
4-Nitroaniline	mg/kg	< 0.1	NONE	< 0.1			
4-Bromophenyl phenyl ether	mg/kg	< 0.1	**MCERTS**	< 0.1			
Hexachlorobenzene	mg/kg	< 0.1	**MCERTS**	< 0.1			
2,4-Dinitrotoluene	mg/kg	< 0.1	**MCERTS**	< 0.1			
Diethyl phthalate	mg/kg	< 0.1	**MCERTS**	< 0.1			
Dibenzofuran	mg/kg	< 0.1	**MCERTS**	< 0.1			
Azobenzene	mg/kg	< 0.1	NONE	< 0.1			
Dibutyl phthalate	mg/kg	< 0.15	**ISO17025**	< 0.15			
Carbazole	mg/kg	< 0.1	**ISO17025**	< 0.1			
bis(2-ethylhexyl)phthalate	mg/kg	< 0.2	**MCERTS**	< 0.2			
Benzyl butyl phthalate	mg/kg	< 0.1	**MCERTS**	< 0.1			
Di-n-octyl phthalate	mg/kg	< 0.1	**MCERTS**	< 0.1			

Analytical results are expressed on a dry weight basis where samples are dried at less than 30^{O}C

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Soil Analysis Certificate - Semi Volatile Organic Compounds TIC (SVOC)		
QTS Environmental Report No: 14-25397	**Date Sampled**	None Supplied
Soil Consultants Ltd	**Time Sampled**	None Supplied
Site Reference: Bedford Avenue	**TP / BH No**	TP12
Project / Job Ref: None Supplied	**Additional Refs**	None Supplied
Order No: None Supplied	**Depth (m)**	0.65
Reporting Date: 05/11/2014	**QTSE Sample No**	120671

Compound No	Compound Name	% Match	Units	RL	Estimated Concentration
1	N/a	N/a	mg/kg	< 0.1	< 0.1
2	N/a	N/a	mg/kg	< 0.1	< 0.1
3	N/a	N/a	mg/kg	< 0.1	< 0.1
4	N/a	N/a	mg/kg	< 0.1	< 0.1
5	N/a	N/a	mg/kg	< 0.1	< 0.1

There were no / other compounds identified with a match of >90%

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Soil Analysis Certificate - PCB (7 Congeners)						
QTS Environmental Report No: 14-25397	**Date Sampled**	None Supplied				
Soil Consultants Ltd	**Time Sampled**	None Supplied				
Site Reference: Bedford Avenue	**TP / BH No**	TP12				
Project / Job Ref: None Supplied	**Additional Refs**	None Supplied				
Order No: None Supplied	**Depth (m)**	0.65				
Reporting Date: 05/11/2014	**QTSE Sample No**	120671				

Determinand	**Unit**	**RL**	**Accreditation**					
PCB Congener 28	mg/kg	< 0.008	NONE	< 0.008				
PCB Congener 52	mg/kg	< 0.008	NONE	< 0.008				
PCB Congener 101	mg/kg	< 0.008	NONE	< 0.008				
PCB Congener 118	mg/kg	< 0.008	NONE	< 0.008				
PCB Congener 138	mg/kg	< 0.008	NONE	< 0.008				
PCB Congener 153	mg/kg	< 0.008	NONE	< 0.008				
PCB Congener 180	mg/kg	< 0.008	NONE	< 0.008				
Total PCB (7 Congeners)	mg/kg	< 0.1	NONE	< 0.1				

Analytical results are expressed on a dry weight basis where samples are dried at less than 30^{O}C

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Soil Analysis Certificate - Sample Descriptions

QTS Environmental Report No: 14-25397
Soil Consultants Ltd
Site Reference: Bedford Avenue
Project / Job Ref: None Supplied
Order No: None Supplied
Reporting Date: 05/11/2014

QTSE Sample No	TP / BH No	Additional Refs	Depth (m)	Moisture Content (%)	Sample Matrix Description
^ 120671	TP12	None Supplied	0.65	6.7	Light brown clayey gravel with stones

Moisture content is part of procedure E003 & is not an accredited test

Insufficient Sample $^{I/S}$

Unsuitable Sample $^{U/S}$

^ no sampling date provided; unable to confirm if samples are within acceptable holding times

Soil Analysis Certificate - Methodology & Miscellaneous Information

QTS Environmental Report No: 14-25397
Soil Consultants Ltd
Site Reference: Bedford Avenue
Project / Job Ref: None Supplied
Order No: None Supplied
Reporting Date: 05/11/2014

Matrix	Analysed On	Determinand	Brief Method Description	Method No
Soil	D	Boron - Water Soluble	Determination of water soluble boron in soil by 2:1 hot water extract followed by ICP-OES	E012
Soil	AR	BTEX	Determination of BTEX by headspace GC-MS	E001
Soil	D	Cations	Determination of cations in soil by aqua-regia digestion followed by ICP-OES	E002
Soil	D	Chloride - Water Soluble (2:1)	Determination of chloride by extraction with water & analysed by ion chromatography	E009
Soil	AR	Chromium - Hexavalent	Determination of hexavalent chromium in soil by extraction in water then by acidification, addition of 1,5 diphenylcarbazide followed by colorimetry	E016
Soil	AR	Cyanide - Complex	Determination of complex cyanide by distillation followed by colorimetry	E015
Soil	AR	Cyanide - Free	Determination of free cyanide by distillation followed by colorimetry	E015
Soil	AR	Cyanide - Total	Determination of total cyanide by distillation followed by colorimetry	E015
Soil	D	Cyclohexane Extractable Matter (CEM)	Gravimetrically determined through extraction with cyclohexane	E011
Soil	AR	Diesel Range Organics (C10 - C24)	Determination of hexane/acetone extractable hydrocarbons by GC-FID	E004
Soil	AR	Electrical Conductivity	Determination of electrical conductivity by addition of saturated calcium sulphate followed by electrometric measurement	E022
Soil	AR	Electrical Conductivity	Determination of electrical conductivity by addition of water followed by electrometric measurement	E023
Soil	D	Elemental Sulphur	Determination of elemental sulphur by solvent extraction followed by GC-MS	E020
Soil	AR	EPH (C10 – C40)	Determination of acetone/hexane extractable hydrocarbons by GC-FID	E004
Soil	AR	EPH Product ID	Determination of acetone/hexane extractable hydrocarbons by GC-FID	E004
Soil	AR	EPH TEXAS	Determination of acetone/hexane extractable hydrocarbons by GC-FID	E004
Soil	D	Fluoride - Water Soluble	Determination of Fluoride by extraction with water & analysed by ion chromatography	E009
Soil	D	FOC (Fraction Organic Carbon)	Determination of fraction of organic carbon by oxidising with potassium dichromate followed by titration with iron (II) sulphate	E010
Soil	D	Loss on Ignition @ 450oC	Determination of loss on ignition in soil by gravimetrically with the sample being ignited in a muffle furnace	E019
Soil	D	Magnesium - Water Soluble	Determination of water soluble magnesium by extraction with water followed by ICP-OES	E025
Soil	D	Metals	Determination of metals by aqua-regia digestion followed by ICP-OES	E002
Soil	AR	Mineral Oil (C10 - C40)	Determination of hexane/acetone extractable hydrocarbons by GC-FID fractionating with SPE cartridge	E004
Soil	AR	Moisture Content	Moisture content; determined gravimetrically	E003
Soil	D	Nitrate - Water Soluble (2:1)	Determination of nitrate by extraction with water & analysed by ion chromatography	E009
Soil	D	Organic Matter	Determination of organic matter by oxidising with potassium dichromate followed by titration with iron (II) sulphate	E010
Soil	AR	PAH - Speciated (EPA 16)	Determination of PAH compounds by extraction in acetone and hexane followed by GC-MS with the use of surrogate and internal standards	E005
Soil	AR	PCB - 7 Congeners	Determination of PCB by extraction with acetone and hexane followed by GC-MS	E008
Soil	D	Petroleum Ether Extract (PEE)	Gravimetrically determined through extraction with petroleum ether	E011
Soil	AR	pH	Determination of pH by addition of water followed by electrometric measurement	E007
Soil	AR	Phenols - Total (monohydric)	Determination of phenols by distillation followed by colorimetry	E021
Soil	D	Phosphate - Water Soluble (2:1)	Determination of phosphate by extraction with water & analysed by ion chromatography	E009
Soil	D	Sulphate (as SO4) - Total	Determination of total sulphate by extraction with 10% HCl followed by ICP-OES	E013
Soil	D	Sulphate (as SO4) - Water Soluble (2:1)	Determination of sulphate by extraction with water & analysed by ion chromatography	E009
Soil	D	Sulphate (as SO4) - Water Soluble (2:1)	Determination of water soluble sulphate by extraction with water followed by ICP-OES	E014
Soil	AR	Sulphide	Determination of sulphide by distillation followed by colorimetry	E018
Soil	D	Sulphur - Total	Determination of total sulphur by extraction with aqua-regia followed by ICP-OES	E024
Soil	AR	SVOC	Determination of semi-volatile organic compounds by extraction in acetone and hexane followed by GC-MS	E006
Soil	AR	Thiocyanate (as SCN)	Determination of thiocyanate by extraction in caustic soda followed by acidification followed by addition of ferric nitrate followed by colorimetry	E017
Soil	D	Toluene Extractable Matter (TEM)	Gravimetrically determined through extraction with toluene	E011
Soil	D	Total Organic Carbon (TOC)	Determination of organic matter by oxidising with potassium dichromate followed by titration with iron (II) sulphate	E010
Soil	AR	TPH CWG	Determination of hexane/acetone extractable hydrocarbons by GC-FID fractionating with SPE cartridge	E004
Soil	AR	TPH LQM	Determination of hexane/acetone extractable hydrocarbons by GC-FID fractionating with SPE cartridge	E004
Soil	AR	VOCs	Determination of volatile organic compounds by headspace GC-MS	E001
Soil	AR	VPH (C6 - C10)	Determination of hydrocarbons C6-C10 by headspace GC-MS	E001

D Dried
AR As Received

John Bartley
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QTS Environmental Report No: 14-25909

Site Reference:	Bedford Avenue
Project / Job Ref:	9661
Order No:	None Supplied
Sample Receipt Date:	23/10/2014
Sample Scheduled Date:	23/10/2014
Report Issue Number:	1
Reporting Date:	31/10/2014

Authorised by:

Russell Jarvis
Director
On behalf of QTS Environmental Ltd

Authorised by:

Kevin Old
Director
On behalf of QTS Environmental Ltd

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Water Analysis Certificate						
QTS Environmental Report No: 14-25909	**Date Sampled**	22/10/14	22/10/14			
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied			
Site Reference: Bedford Avenue	**TP / BH No**	WS1	WS2			
Project / Job Ref: 9661	**Additional Refs**	None Supplied	None Supplied			
Order No: None Supplied	**Depth (m)**	None Supplied	None Supplied			
Reporting Date: 31/10/2014	**QTSE Sample No**	123063	123064			

Determinand	**Unit**	**RL**	**Accreditation**					
pH	pH Units	N/a	**ISO17025**	7.4	7.4			
Sulphate as SO_4	mg/l	< 1	**ISO17025**	152	149			
Sulphide	mg/l	< 0.1	NONE	< 0.1	< 0.1			
Ammonium as NH_4	ug/l	< 50	NONE	60	< 50			
Chloride	mg/l	< 1	**ISO17025**	65	85			
Nitrate as NO_3	mg/l	< 0.5	**ISO17025**	32.4	97.1			
Hardness - Total	mgCaCO3/l	< 1	NONE	564	496			
Arsenic (dissolved)	ug/l	< 10	NONE	< 10	< 10			
Barium (dissolved)	ug/l	< 20	NONE	95	127			
Beryllium (dissolved)	ug/l	< 1	NONE	< 1	< 1			
Boron (dissolved)	ug/l	< 50	NONE	132	110			
Cadmium (dissolved)	ug/l	< 0.5	NONE	< 0.5	< 0.5			
Chromium (dissolved)	ug/l	< 5	NONE	< 5	< 5			
Copper (dissolved)	ug/l	< 10	NONE	< 10	< 10			
Iron (dissolved)	ug/l	< 25	NONE	299	150			
Lead (dissolved)	ug/l	< 5	NONE	< 5	< 5			
Mercury (dissolved)	ug/l	< 0.05	NONE	< 0.05	< 0.05			
Nickel (dissolved)	ug/l	< 7	NONE	< 7	< 7			
Selenium (dissolved)	ug/l	< 5	NONE	< 5	< 5			
Vanadium (dissolved)	ug/l	< 5	NONE	< 5	< 5			
Zinc (dissolved)	ug/l	< 5	NONE	< 5	< 5			

Subcontracted analysis $^{(S)}$
Insufficient sample $^{I/S}$
Unsuitable Sample $^{U/S}$

Water Analysis Certificate - Speciated PAH						
QTS Environmental Report No: 14-2	**Date Sampled**	22/10/14	22/10/14			
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied			
Site Reference: Bedford Avenue	**TP / BH No**	WS1	WS2			
Project / Job Ref: 9661	**Additional Refs**	None Supplied	None Supplied			
Order No: None Supplied	**Depth (m)**	None Supplied	None Supplied			
Reporting Date: 31/10/2014	**QTSE Sample No**	123063	123064			

Determinand	**Unit**	**RL**	**Accreditation**					
Naphthalene	ug/l	< 0.01	NONE	< 0.01	< 0.01			
Acenaphthylene	ug/l	< 0.01	NONE	< 0.01	< 0.01			
Acenaphthene	ug/l	< 0.01	NONE	< 0.01	< 0.01			
Fluorene	ug/l	< 0.01	NONE	< 0.01	< 0.01			
Phenanthrene	ug/l	< 0.01	NONE	< 0.01	< 0.01			
Anthracene	ug/l	< 0.01	NONE	< 0.01	< 0.01			
Fluoranthene	ug/l	< 0.01	NONE	< 0.01	< 0.01			
Pyrene	ug/l	< 0.01	NONE	< 0.01	< 0.01			
Benzo(a)anthracene	ug/l	< 0.01	NONE	< 0.01	< 0.01			
Chrysene	ug/l	< 0.01	NONE	< 0.01	< 0.01			
Benzo(b)fluoranthene	ug/l	< 0.01	NONE	< 0.01	< 0.01			
Benzo(k)fluoranthene	ug/l	< 0.01	NONE	< 0.01	< 0.01			
Benzo(a)pyrene	ug/l	< 0.01	NONE	< 0.01	< 0.01			
Indeno(1,2,3-cd)pyrene	ug/l	< 0.01	NONE	< 0.01	< 0.01			
Dibenz(a,h)anthracene	ug/l	< 0.01	NONE	< 0.01	< 0.01			
Benzo(ghi)perylene	ug/l	< 0.01	NONE	< 0.01	< 0.01			
Total EPA-16 PAHs	ug/l	< 0.01	NONE	< 0.01	< 0.01			

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Water Analysis Certificate - TPH CWG Banded

QTS Environmental Report No: 14-25909	**Date Sampled**	22/10/14	22/10/14			
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied			
Site Reference: Bedford Avenue	**TP / BH No**	WS1	WS2			
Project / Job Ref: 9661	**Additional Refs**	None Supplied	None Supplied			
Order No: None Supplied	**Depth (m)**	None Supplied	None Supplied			
Reporting Date: 31/10/2014	**QTSE Sample No**	123063	123064			

Determinand	**Unit**	**RL**	**Accreditation**					
Aliphatic >C5 - C6	ug/l	< 10	NONE	< 10	< 10			
Aliphatic >C6 - C8	ug/l	< 10	NONE	< 10	< 10			
Aliphatic >C8 - C10	ug/l	< 10	NONE	< 10	< 10			
Aliphatic >C10 - C12	ug/l	< 10	NONE	< 10	< 10			
Aliphatic >C12 - C16	ug/l	< 10	NONE	< 10	< 10			
Aliphatic >C16 - C21	ug/l	< 10	NONE	< 10	< 10			
Aliphatic >C21 - C34	ug/l	< 10	NONE	< 10	< 10			
Aliphatic (C5 - C34)	ug/l	< 70	NONE	< 70	< 70			
Aromatic >C5 - C7	ug/l	< 10	NONE	< 10	< 10			
Aromatic >C7 - C8	ug/l	< 10	NONE	< 10	< 10			
Aromatic >C8 - C10	ug/l	< 10	NONE	< 10	< 10			
Aromatic >C10 - C12	ug/l	< 10	NONE	< 10	< 10			
Aromatic >C12 - C16	ug/l	< 10	NONE	< 10	< 10			
Aromatic >C16 - C21	ug/l	< 10	NONE	< 10	< 10			
Aromatic >C21 - C35	ug/l	< 10	NONE	< 10	< 10			
Aromatic (C5 - C35)	ug/l	< 70	NONE	< 70	< 70			
Total >C5 - C35	ug/l	< 140	NONE	< 140	< 140			

Water Analysis Certificate - BTEX / MTBE

QTS Environmental Report No: 14-25909	**Date Sampled**	22/10/14	22/10/14			
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied			
Site Reference: Bedford Avenue	**TP / BH No**	WS1	WS2			
Project / Job Ref: 9661	**Additional Refs**	None Supplied	None Supplied			
Order No: None Supplied	**Depth (m)**	None Supplied	None Supplied			
Reporting Date: 31/10/2014	**QTSE Sample No**	123063	123064			

Determinand	**Unit**	**RL**	**Accreditation**					
Benzene	ug/l	< 1	**ISO17025**	< 1	< 1			
Toluene	ug/l	< 5	**ISO17025**	< 5	< 5			
Ethylbenzene	ug/l	< 5	**ISO17025**	< 5	< 5			
p & m-xylene	ug/l	< 10	**ISO17025**	< 10	< 10			
o-xylene	ug/l	< 5	**ISO17025**	< 5	< 5			
MTBE	ug/l	< 10	**ISO17025**	< 10	< 10			

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Water Analysis Certificate - Volatile Organic Compounds (VOC)

QTS Environmental Report No: 14-25909	**Date Sampled**	22/10/14	22/10/14			
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied			
Site Reference: Bedford Avenue	**TP / BH No**	WS1	WS2			
Project / Job Ref: 9661	**Additional Refs**	None Supplied	None Supplied			
Order No: None Supplied	**Depth (m)**	None Supplied	None Supplied			
Reporting Date: 31/10/2014	**QTSE Sample No**	123063	123064			

Determinand	**Unit**	**RL**	**Accreditation**					
Dichlorodifluoromethane	ug/l	< 5	ISO17025	< 5	< 5			
Vinyl Chloride	ug/l	< 5	ISO17025	< 5	< 5			
Chloromethane	ug/l	< 5	ISO17025	< 5	< 5			
Chloroethane	ug/l	< 5	ISO17025	< 5	< 5			
Bromomethane	ug/l	< 5	ISO17025	< 5	< 5			
Trichlorofluoromethane	ug/l	< 5	ISO17025	< 5	< 5			
1,1-Dichloroethene	ug/l	< 5	ISO17025	< 5	< 5			
MTBE	ug/l	< 10	ISO17025	< 10	< 10			
trans-1,2-Dichloroethene	ug/l	< 5	ISO17025	< 5	< 5			
1,1-Dichloroethane	ug/l	< 5	ISO17025	< 5	< 5			
cis-1,2-Dichloroethene	ug/l	< 5	ISO17025	< 5	< 5			
2,2-Dichloropropane	ug/l	< 5	ISO17025	< 5	< 5			
Chloroform	ug/l	< 5	ISO17025	< 5	< 5			
Bromochloromethane	ug/l	< 10	ISO17025	< 10	< 10			
1,1,1-Trichloroethane	ug/l	< 5	ISO17025	< 5	< 5			
1,1-Dichloropropene	ug/l	< 5	ISO17025	< 5	< 5			
Carbon Tetrachloride	ug/l	< 5	ISO17025	< 5	< 5			
1,2-Dichloroethane	ug/l	< 10	ISO17025	< 10	< 10			
Benzene	ug/l	< 1	ISO17025	< 1	< 1			
1,2-Dichloropropane	ug/l	< 5	ISO17025	< 5	< 5			
Trichloroethene	ug/l	< 5	ISO17025	< 5	< 5			
Bromodichloromethane	ug/l	< 5	ISO17025	< 5	< 5			
Dibromomethane	ug/l	< 5	ISO17025	< 5	< 5			
TAME	ug/l	< 5	ISO17025	< 5	< 5			
cis-1,3-Dichloropropene	ug/l	< 5	ISO17025	< 5	< 5			
Toluene	ug/l	< 5	ISO17025	< 5	< 5			
trans-1,3-Dichloropropene	ug/l	< 5	ISO17025	< 5	< 5			
1,1,2-Trichloroethane	ug/l	< 10	ISO17025	< 10	< 10			
1,3-Dichloropropane	ug/l	< 5	ISO17025	< 5	< 5			
Tetrachloroethene	ug/l	< 5	ISO17025	< 5	< 5			
Dibromochloromethane	ug/l	< 5	ISO17025	< 5	< 5			
1,2-Dibromoethane	ug/l	< 5	ISO17025	< 5	< 5			
Chlorobenzene	ug/l	< 5	ISO17025	< 5	< 5			
1,1,1,2-Tetrachloroethane	ug/l	< 5	ISO17025	< 5	< 5			
Ethyl Benzene	ug/l	< 5	ISO17025	< 5	< 5			
m,p-Xylene	ug/l	< 10	ISO17025	< 10	< 10			
o-Xylene	ug/l	< 5	ISO17025	< 5	< 5			
Styrene	ug/l	< 5	ISO17025	< 5	< 5			
Bromoform	ug/l	< 10	ISO17025	< 10	< 10			
Isopropylbenzene	ug/l	< 5	ISO17025	< 5	< 5			
1,1,2,2-Tetrachloroethane	ug/l	< 10	ISO17025	< 10	< 10			
1,2,3-Trichloropropane	ug/l	< 5	ISO17025	< 5	< 5			
n-Propylbenzene	ug/l	< 5	ISO17025	< 5	< 5			
Bromobenzene	ug/l	< 5	ISO17025	< 5	< 5			
2-Chlorotoluene	ug/l	< 5	ISO17025	< 5	< 5			
1,3,5-Trimethylbenzene	ug/l	< 5	ISO17025	< 5	< 5			
4-Chlorotoluene	ug/l	< 5	ISO17025	< 5	< 5			
tert-Butylbenzene	ug/l	< 5	ISO17025	< 5	< 5			
1,2,4-Trimethylbenzene	ug/l	< 5	ISO17025	< 5	< 5			
sec-Butylbenzene	ug/l	< 5	ISO17025	< 5	< 5			
p-Isopropyltoluene	ug/l	< 5	ISO17025	< 5	< 5			
1,3-Dichlorobenzene	ug/l	< 5	ISO17025	< 5	< 5			
1,4-Dichlorobenzene	ug/l	< 5	ISO17025	< 5	< 5			
n-Butylbenzene	ug/l	< 5	ISO17025	< 5	< 5			
1,2-Dichlorobenzene	ug/l	< 5	ISO17025	< 5	< 5			
1,2-Dibromo-3-chloropropane	ug/l	< 10	ISO17025	< 10	< 10			
Hexachlorobutadiene	ug/l	< 5	ISO17025	< 5	< 5			

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Water Analysis Certificate - Volatile Organic Compounds TIC (VOC)

QTS Environmental Report No: 14-25909	**Date Sampled**	22/10/14
Soil Consultants Ltd	**Time Sampled**	None Supplied
Site Reference: Bedford Avenue	**TP / BH No**	WS1
Project / Job Ref: 9661	**Additional Refs**	None Supplied
Order No: None Supplied	**Depth (m)**	None Supplied
Reporting Date: 31/10/2014	**QTSE Sample No**	123063

Compound No	Compound Name	% Match	Units	RL	Estimated Concentration
1	N/a	N/a	µg/l	< 5	< 5
2	N/a	N/a	µg/l	< 5	< 5
3	N/a	N/a	µg/l	< 5	< 5
4	N/a	N/a	µg/l	< 5	< 5
5	N/a	N/a	µg/l	< 5	< 5

There were no / other compounds identified with a match of >90%

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Water Analysis Certificate - Volatile Organic Compounds TIC (VOC)

QTS Environmental Report No: 14-25909	**Date Sampled**	22/10/14
Soil Consultants Ltd	**Time Sampled**	None Supplied
Site Reference: Bedford Avenue	**TP / BH No**	WS2
Project / Job Ref: 9661	**Additional Refs**	None Supplied
Order No: None Supplied	**Depth (m)**	None Supplied
Reporting Date: 31/10/2014	**QTSE Sample No**	123064

Compound No	Compound Name	% Match	Units	RL	Estimated Concentration
1	N/a	N/a	µg/l	< 5	< 5
2	N/a	N/a	µg/l	< 5	< 5
3	N/a	N/a	µg/l	< 5	< 5
4	N/a	N/a	µg/l	< 5	< 5
5	N/a	N/a	µg/l	< 5	< 5

There were no / other compounds identified with a match of >90%

Water Analysis Certificate - Semi Volatile Organic Compounds (SVOC)

QTS Environmental Report No: 14-25909	**Date Sampled**	22/10/14	22/10/14			
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied			
Site Reference: Bedford Avenue	**TP / BH No**	WS1	WS2			
Project / Job Ref: 9661	**Additional Refs**	None Supplied	None Supplied			
Order No: None Supplied	**Depth (m)**	None Supplied	None Supplied			
Reporting Date: 31/10/2014	**QTSE Sample No**	123063	123064			

Determinand	**Unit**	**RL**	**Accreditation**					
Phenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
1,2,4-Trichlorobenzene	ug/l	< 0.1	NONE	< 0.1	< 0.1			
2-Nitrophenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
Nitrobenzene	ug/l	< 0.1	NONE	< 0.1	< 0.1			
0-Cresol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
bis(2-chloroethoxy)methane	ug/l	< 0.1	NONE	< 0.1	< 0.1			
bis(2-chloroethyl)ether	ug/l	< 0.1	NONE	< 0.1	< 0.1			
2,4-Dichlorophenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
2-Chlorophenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
1,3-Dichlorobenzene	ug/l	< 0.1	NONE	< 0.1	< 0.1			
1,4-Dichlorobenzene	ug/l	< 0.1	NONE	< 0.1	< 0.1			
1,2-Dichlorobenzene	ug/l	< 0.1	NONE	< 0.1	< 0.1			
2,4-Dimethylphenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
Isophorone	ug/l	< 0.1	NONE	< 0.1	< 0.1			
Hexachloroethane	ug/l	< 0.1	NONE	< 0.1	< 0.1			
p-Cresol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
2,4,6-Trichlorophenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
2,4,5-Trichlorophenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
2-Nitroaniline	ug/l	< 0.1	NONE	< 0.1	< 0.1			
4-Chloro-3-methylphenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
2-Methylnaphthalene	ug/l	< 0.1	NONE	< 0.1	< 0.1			
Hexachlorocyclopentadiene	ug/l	< 0.1	NONE	< 0.1	< 0.1			
Hexachlorobutadiene	ug/l	< 0.1	NONE	< 0.1	< 0.1			
2,6-Dinitrotoluene	ug/l	< 0.1	NONE	< 0.1	< 0.1			
Dimethyl phthalate	ug/l	< 0.1	NONE	< 0.1	< 0.1			
2-Chloronaphthalene	ug/l	< 0.1	NONE	< 0.1	< 0.1			
4-Chloroanaline	ug/l	< 0.1	NONE	< 0.1	< 0.1			
4-Nitrophenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
4-Chlorophenyl phenyl ether	ug/l	< 0.1	NONE	< 0.1	< 0.1			
3-Nitroaniline	ug/l	< 0.1	NONE	< 0.1	< 0.1			
4-Nitroaniline	ug/l	< 0.1	NONE	< 0.1	< 0.1			
4-Bromophenyl phenyl ether	ug/l	< 0.1	NONE	< 0.1	< 0.1			
Hexachlorobenzene	ug/l	< 0.1	NONE	< 0.1	< 0.1			
2,4-Dinitrotoluene	ug/l	< 0.1	NONE	< 0.1	< 0.1			
Diethyl phthalate	ug/l	< 0.1	NONE	< 0.1	< 0.1			
Dibenzofuran	ug/l	< 0.1	NONE	< 0.1	< 0.1			
Azobenzene	ug/l	< 0.1	NONE	< 0.1	< 0.1			
Dibutyl phthalate	ug/l	< 0.1	NONE	< 0.1	< 0.1			
Carbazole	ug/l	< 0.1	NONE	< 0.1	< 0.1			
bis(2-ethylhexyl)phthalate	ug/l	< 0.1	NONE	< 0.1	< 0.1			
Benzyl butyl phthalate	ug/l	< 0.1	NONE	< 0.1	< 0.1			
Di-n-octyl phthalate	ug/l	< 0.1	NONE	< 0.1	< 0.1			

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Water Analysis Certificate - Semi Volatile Organic Compounds TIC (SVOC)

QTS Environmental Report No: 14-25909	**Date Sampled**	22/10/14
Soil Consultants Ltd	**Time Sampled**	None Supplied
Site Reference: Bedford Avenue	**TP / BH No**	WS1
Project / Job Ref: 9661	**Additional Refs**	None Supplied
Order No: None Supplied	**Depth (m)**	None Supplied
Reporting Date: 31/10/2014	**QTSE Sample No**	123063

Compound No	Compound Name	% Match	Units	RL	Estimated Concentration
1	N/a	N/a	µg/l	< 0.1	< 0.1
2	N/a	N/a	µg/l	< 0.1	< 0.1
3	N/a	N/a	µg/l	< 0.1	< 0.1
4	N/a	N/a	µg/l	< 0.1	< 0.1
5	N/a	N/a	µg/l	< 0.1	< 0.1

There were no / other compounds identified with a match of >90%

Water Analysis Certificate - Semi Volatile Organic Compounds TIC (SVOC)

QTS Environmental Report No: 14-25909	**Date Sampled**	22/10/14
Soil Consultants Ltd	**Time Sampled**	None Supplied
Site Reference: Bedford Avenue	**TP / BH No**	WS2
Project / Job Ref: 9661	**Additional Refs**	None Supplied
Order No: None Supplied	**Depth (m)**	None Supplied
Reporting Date: 31/10/2014	**QTSE Sample No**	123064

Compound No	Compound Name	% Match	Units	RL	Estimated Concentration
1	N/a	N/a	µg/l	< 0.1	< 0.1
2	N/a	N/a	µg/l	< 0.1	< 0.1
3	N/a	N/a	µg/l	< 0.1	< 0.1
4	N/a	N/a	µg/l	< 0.1	< 0.1
5	N/a	N/a	µg/l	< 0.1	< 0.1

There were no / other compounds identified with a match of >90%

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Water Analysis Certificate - PCB (7 Congeners)

QTS Environmental Report No: 14-25909	**Date Sampled**	22/10/14	22/10/14			
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied			
Site Reference: Bedford Avenue	**TP / BH No**	WS1	WS2			
Project / Job Ref: 9661	**Additional Refs**	None Supplied	None Supplied			
Order No: None Supplied	**Depth (m)**	None Supplied	None Supplied			
Reporting Date: 31/10/2014	**QTSE Sample No**	123063	123064			

Determinand	**Unit**	**RL**	**Accreditation**					
PCB Congener 28	ug/l	< 0.1	NONE	< 0.1	< 0.1			
PCB Congener 52	ug/l	< 0.1	NONE	< 0.1	< 0.1			
PCB Congener 101	ug/l	< 0.1	NONE	< 0.1	< 0.1			
PCB Congener 118	ug/l	< 0.1	NONE	< 0.1	< 0.1			
PCB Congener 138	ug/l	< 0.1	NONE	< 0.1	< 0.1			
PCB Congener 153	ug/l	< 0.1	NONE	< 0.1	< 0.1			
PCB Congener 180	ug/l	< 0.1	NONE	< 0.1	< 0.1			
Total PCB (7 Congeners)	ug/l	< 0.7	NONE	< 0.7	< 0.7			

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Water Analysis Certificate - Speciated Phenols						
QTS Environmental Report No: 14-25909	**Date Sampled**	22/10/14	22/10/14			
Soil Consultants Ltd	**Time Sampled**	None Supplied	None Supplied			
Site Reference: Bedford Avenue	**TP / BH No**	WS1	WS2			
Project / Job Ref: 9661	**Additional Refs**	None Supplied	None Supplied			
Order No: None Supplied	**Depth (m)**	None Supplied	None Supplied			
Reporting Date: 31/10/2014	**QTSE Sample No**	123063	123064			

Determinand	**Unit**	**RL**	**Accreditation**					
2, 3, 5-trimethylphenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
2, 3, 6-trimethylphenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
2, 3-xylenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
2, 4, 6-trimethylphenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
2, 4-xylenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
2, 5-xylenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
2, 6-xylenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
2-ethylphenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
2-isopropylphenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
3, 4, 5-trimethylphenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
3, 4-xylenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
3, 5-xylenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
3-ethylphenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
3-isopropylphenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
4-ethylphenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
4-isopropylphenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			
m-cresol (3-methylphenol)	ug/l	< 0.1	NONE	< 0.1	< 0.1			
o-cresol (2-methylphenol)	ug/l	< 0.1	NONE	< 0.1	< 0.1			
p-cresol (4-methylphenol)	ug/l	< 0.1	NONE	< 0.1	< 0.1			
phenol	ug/l	< 0.1	NONE	< 0.1	< 0.1			

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Soil Analysis Certificate - Methodology & Miscellaneous Information
QTS Environmental Report No: 14-25909
Soil Consultants Ltd
Site Reference: Bedford Avenue
Project / Job Ref: 9661
Order No: None Supplied
Reporting Date: 31/10/2014

Matrix	Analysed On	Determinand	Brief Method Description	Method No
Water	UF	Alkalinity	Determination of alkalinity by titration against hydrochloric acid using bromocresol green as the end point	E103
Water	UF	BTEX	Determination of BTEX by headspace GC-MS	E101
Water	F	Cations	Determination of cations by filtration followed by ICP-MS	E102
Water	UF	Chemical Oxygen Demand (COD)	Determination using a COD reactor followed by colorimetry	E112
Water	F	Chloride	Determination of chloride by filtration & analysed by ion chromatography	E109
Water	F	Chromium - Hexavalent	Determination of hexavalent chromium by acidification, addition of 1,5 diphenylcarbazide followed by colo	E116
Water	UF	Cyanide - Complex	Determination of complex cyanide by distillation followed by colorimetry	E115
Water	UF	Cyanide - Free	Determination of free cyanide by distillation followed by colorimetry	E115
Water	UF	Cyanide - Total	Determination of total cyanide by distillation followed by colorimetry	E115
Water	UF	Cyclohexane Extractable Matter (CEM)	Gravimetrically determined through liquid:liquid extraction with cyclohexane	E111
Water	F	Diesel Range Organics (C10 - C24)	Determination of liquid:liquid extraction with hexane followed by GI-FID	E104
Water	F	Dissolved Organic Content (DOC)	Determination of DOC by filtration followed by low heat with persulphate addition followed by IR detection	E110
Water	UF	Electrical Conductivity	Determination of electrical conductivity by electrometric measurement	E123
Water	F	EPH (C10 – C40)	Determination of liquid:liquid extraction with hexane followed by GI-FID	E104
Water	F	EPH TEXAS	Determination of liquid:liquid extraction with hexane followed by GI-FID	E104
Water	F	Fluoride	Determination of Fluoride by filtration & analysed by ion chromatography	E109
Water	F	Hardness	Determination of Ca and Mg by ICP-MS followed by calculation	E102
Leachate	F	Leachate Preparation - NRA	Based on National Rivers Authority leaching test 1994	E301
Leachate	F	Leachate Preparation - WAC	Based on BS EN 12457 Pt1, 2, 3	E302
Water	F	Metals	Determination of metals by filtration followed by ICP-MS	E102
Water	F	Mineral Oil (C10 - C40)	Determination of liquid:liquid extraction with hexane followed by GI-FID	E104
Water	F	Nitrate	Determination of nitrate by filtration & analysed by ion chromatography	E109
Water	UF	Monohydric Phenol	Determination of phenols by distillation followed by colorimetry	E121
Water	F	PAH - Speciated (EPA 16)	Determination of PAH compounds by concentration through SPE cartridge, collection in dichloromethane followed by GC-MS	E105
Water	F	PCB - 7 Congeners	Determination of PCB compounds by concentration through SPE cartridge, collection in dichloromethane f	E108
Water	UF	Petroleum Ether Extract (PEE)	Gravimetrically determined through liquid:liquid extraction with petroleum ether	E111
Water	UF	pH	Determination of pH by electrometric measurement	E107
Water	F	Phosphate	Determination of phosphate by filtration & analysed by ion chromatography	E109
Water	UF	Redox Potential	Determination of redox potential by electrometric measurement	E113
Water	F	Sulphate (as SO4)	Determination of sulphate by filtration & analysed by ion chromatography	E109
Water	UF	Sulphide	Determination of sulphide by distillation followed by colorimetry	E118
Water	F	SVOC	Determination of semi-volatile organic compounds by concentration through SPE cartridge, collection in dichloromethane followed by GC-MS	E106
Water	UF	Toluene Extractable Matter (TEM)	Gravimetrically determined through liquid:liquid extraction with toluene	E111
Water	UF	Total Organic Carbon (TOC)	Low heat with persulphate addition followed by IR detection	E110
Water	F	TPH CWG	Determination of liquid:liquid extraction with hexane, fractionating with SPE followed by GC-FID	E104
Water	F	TPH LQM	Determination of liquid:liquid extraction with hexane, fractionating with SPE followed by GC-FID	E104
Water	UF	VOCs	Determination of volatile organic compounds by headspace GC-MS	E101
Water	UF	VPH (C6 - C10)	Determination of hydrocarbons C6-C10 by headspace GC-MS	E101

Key

F Filtered
UF Unfiltered

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QTS Environmental Report No: 14-26770

Site Reference: Bedford Avenue

Project / Job Ref: 9661

Order No: None Supplied

Sample Receipt Date: 20/11/2014

Sample Scheduled Date: 21/11/2014

Report Issue Number: 1

Reporting Date: 27/11/2014

Authorised by:

Russell Jarvis
Director
On behalf of QTS Environmental Ltd

Authorised by:

Kevin Old
Director
On behalf of QTS Environmental Ltd

Water Analysis Certificate						
QTS Environmental Report No: 14-26770	**Date Sampled**	None Supplied				
Soil Consultants Ltd	**Time Sampled**	None Supplied				
Site Reference: Bedford Avenue	**TP / BH No**	BH2				
Project / Job Ref: 9661	**Additional Refs**	W1				
Order No: None Supplied	**Depth (m)**	None Supplied				
Reporting Date: 27/11/2014	**QTSE Sample No**	126661				

Determinand	**Unit**	**RL**	**Accreditation**					
pH	pH Units	N/a	**ISO17025**	7.5				
Sulphate as SO_4	mg/l	< 1	**ISO17025**	163				
Sulphide	mg/l	< 0.1	NONE	< 0.1				
Ammonium as NH_4	ug/l	< 50	NONE	< 50				
Chloride	mg/l	< 1	**ISO17025**	85				
Nitrate as NO_3	mg/l	< 0.5	**ISO17025**	115				
Hardness - Total	mgCaCO3/l	< 1	NONE	503				
Arsenic (dissolved)	ug/l	< 5	NONE	< 5				
Barium (dissolved)	ug/l	< 5	NONE	116				
Beryllium (dissolved)	ug/l	< 3	NONE	< 3				
Boron (dissolved)	ug/l	< 5	NONE	149				
Cadmium (dissolved)	ug/l	< 0.4	NONE	< 0.4				
Chromium (dissolved)	ug/l	< 5	NONE	10				
Copper (dissolved)	ug/l	< 5	NONE	< 5				
Iron (dissolved)	ug/l	< 5	NONE	< 5				
Lead (dissolved)	ug/l	< 5	NONE	< 5				
Mercury (dissolved)	ug/l	< 0.05	NONE	< 0.05				
Nickel (dissolved)	ug/l	< 5	NONE	< 5				
Selenium (dissolved)	ug/l	< 5	NONE	< 5				
Vanadium (dissolved)	ug/l	< 5	NONE	< 5				
Zinc (dissolved)	ug/l	< 2	NONE	4				

Subcontracted analysis $^{(S)}$
Insufficient sample $^{I/S}$
Unsuitable Sample $^{U/S}$

Water Analysis Certificate - Speciated PAH						
QTS Environmental Report No: 14-2	**Date Sampled**	None Supplied				
Soil Consultants Ltd	**Time Sampled**	None Supplied				
Site Reference: Bedford Avenue	**TP / BH No**	BH2				
Project / Job Ref: 9661	**Additional Refs**	W1				
Order No: None Supplied	**Depth (m)**	None Supplied				
Reporting Date: 27/11/2014	**QTSE Sample No**	126661				

Determinand	**Unit**	**RL**	**Accreditation**				
Naphthalene	ug/l	< 0.01	NONE	< 0.01			
Acenaphthylene	ug/l	< 0.01	NONE	< 0.01			
Acenaphthene	ug/l	< 0.01	NONE	< 0.01			
Fluorene	ug/l	< 0.01	NONE	< 0.01			
Phenanthrene	ug/l	< 0.01	NONE	< 0.01			
Anthracene	ug/l	< 0.01	NONE	< 0.01			
Fluoranthene	ug/l	< 0.01	NONE	< 0.01			
Pyrene	ug/l	< 0.01	NONE	< 0.01			
Benzo(a)anthracene	ug/l	< 0.01	NONE	< 0.01			
Chrysene	ug/l	< 0.01	NONE	< 0.01			
Benzo(b)fluoranthene	ug/l	< 0.01	NONE	< 0.01			
Benzo(k)fluoranthene	ug/l	< 0.01	NONE	< 0.01			
Benzo(a)pyrene	ug/l	< 0.01	NONE	< 0.01			
Indeno(1,2,3-cd)pyrene	ug/l	< 0.01	NONE	< 0.01			
Dibenz(a,h)anthracene	ug/l	< 0.01	NONE	< 0.01			
Benzo(ghi)perylene	ug/l	< 0.01	NONE	< 0.01			
Total EPA-16 PAHs	ug/l	< 0.01	NONE	< 0.01			

Water Analysis Certificate - TPH CWG Banded

QTS Environmental Report No: 14-26770	**Date Sampled**	None Supplied				
Soil Consultants Ltd	**Time Sampled**	None Supplied				
Site Reference: Bedford Avenue	**TP / BH No**	BH2				
Project / Job Ref: 9661	**Additional Refs**	W1				
Order No: None Supplied	**Depth (m)**	None Supplied				
Reporting Date: 27/11/2014	**QTSE Sample No**	126661				

Determinand	**Unit**	**RL**	**Accreditation**					
Aliphatic >C5 - C6	ug/l	< 10	NONE	< 10				
Aliphatic >C6 - C8	ug/l	< 10	NONE	< 10				
Aliphatic >C8 - C10	ug/l	< 10	NONE	< 10				
Aliphatic >C10 - C12	ug/l	< 10	NONE	< 10				
Aliphatic >C12 - C16	ug/l	< 10	NONE	< 10				
Aliphatic >C16 - C21	ug/l	< 10	NONE	< 10				
Aliphatic >C21 - C34	ug/l	< 10	NONE	< 10				
Aliphatic (C5 - C34)	ug/l	< 70	NONE	< 70				
Aromatic >C5 - C7	ug/l	< 10	NONE	< 10				
Aromatic >C7 - C8	ug/l	< 10	NONE	< 10				
Aromatic >C8 - C10	ug/l	< 10	NONE	< 10				
Aromatic >C10 - C12	ug/l	< 10	NONE	< 10				
Aromatic >C12 - C16	ug/l	< 10	NONE	< 10				
Aromatic >C16 - C21	ug/l	< 10	NONE	< 10				
Aromatic >C21 - C35	ug/l	< 10	NONE	< 10				
Aromatic (C5 - C35)	ug/l	< 70	NONE	< 70				
Total >C5 - C35	ug/l	< 140	NONE	< 140				

Water Analysis Certificate - BTEX / MTBE						
QTS Environmental Report No: 14-26770	**Date Sampled**	None Supplied				
Soil Consultants Ltd	**Time Sampled**	None Supplied				
Site Reference: Bedford Avenue	**TP / BH No**	BH2				
Project / Job Ref: 9661	**Additional Refs**	W1				
Order No: None Supplied	**Depth (m)**	None Supplied				
Reporting Date: 27/11/2014	**QTSE Sample No**	126661				

Determinand	**Unit**	**RL**	**Accreditation**					
Benzene	ug/l	< 1	**ISO17025**	< 1				
Toluene	ug/l	< 5	**ISO17025**	< 5				
Ethylbenzene	ug/l	< 5	**ISO17025**	< 5				
p & m-xylene	ug/l	< 10	**ISO17025**	< 10				
o-xylene	ug/l	< 5	**ISO17025**	< 5				
MTBE	ug/l	< 10	**ISO17025**	< 10				

Water Analysis Certificate - Volatile Organic Compounds (VOC)

QTS Environmental Report No: 14-26770	**Date Sampled**	None Supplied				
Soil Consultants Ltd	**Time Sampled**	None Supplied				
Site Reference: Bedford Avenue	**TP / BH No**	BH2				
Project / Job Ref: 9661	**Additional Refs**	W1				
Order No: None Supplied	**Depth (m)**	None Supplied				
Reporting Date: 27/11/2014	**QTSE Sample No**	126661				

Determinand	**Unit**	**RL**	**Accreditation**					
Dichlorodifluoromethane	ug/l	< 5	ISO17025	< 5				
Vinyl Chloride	ug/l	< 5	ISO17025	< 5				
Chloromethane	ug/l	< 5	ISO17025	< 5				
Chloroethane	ug/l	< 5	ISO17025	< 5				
Bromomethane	ug/l	< 5	ISO17025	< 5				
Trichlorofluoromethane	ug/l	< 5	ISO17025	< 5				
1,1-Dichloroethene	ug/l	< 5	ISO17025	< 5				
MTBE	ug/l	< 10	ISO17025	< 10				
trans-1,2-Dichloroethene	ug/l	< 5	ISO17025	< 5				
1,1-Dichloroethane	ug/l	< 5	ISO17025	< 5				
cis-1,2-Dichloroethene	ug/l	< 5	ISO17025	< 5				
2,2-Dichloropropane	ug/l	< 5	ISO17025	< 5				
Chloroform	ug/l	< 5	ISO17025	< 5				
Bromochloromethane	ug/l	< 10	ISO17025	< 10				
1,1,1-Trichloroethane	ug/l	< 5	ISO17025	< 5				
1,1-Dichloropropene	ug/l	< 5	ISO17025	< 5				
Carbon Tetrachloride	ug/l	< 5	ISO17025	< 5				
1,2-Dichloroethane	ug/l	< 10	ISO17025	< 10				
Benzene	ug/l	< 1	ISO17025	< 1				
1,2-Dichloropropane	ug/l	< 5	ISO17025	< 5				
Trichloroethene	ug/l	< 5	ISO17025	< 5				
Bromodichloromethane	ug/l	< 5	ISO17025	< 5				
Dibromomethane	ug/l	< 5	ISO17025	< 5				
TAME	ug/l	< 5	ISO17025	< 5				
cis-1,3-Dichloropropene	ug/l	< 5	ISO17025	< 5				
Toluene	ug/l	< 5	ISO17025	< 5				
trans-1,3-Dichloropropene	ug/l	< 5	ISO17025	< 5				
1,1,2-Trichloroethane	ug/l	< 10	ISO17025	< 10				
1,3-Dichloropropane	ug/l	< 5	ISO17025	< 5				
Tetrachloroethene	ug/l	< 5	ISO17025	< 5				
Dibromochloromethane	ug/l	< 5	ISO17025	< 5				
1,2-Dibromoethane	ug/l	< 5	ISO17025	< 5				
Chlorobenzene	ug/l	< 5	ISO17025	< 5				
1,1,1,2-Tetrachloroethane	ug/l	< 5	ISO17025	< 5				
Ethyl Benzene	ug/l	< 5	ISO17025	< 5				
m,p-Xylene	ug/l	< 10	ISO17025	< 10				
o-Xylene	ug/l	< 5	ISO17025	< 5				
Styrene	ug/l	< 5	ISO17025	< 5				
Bromoform	ug/l	< 10	ISO17025	< 10				
Isopropylbenzene	ug/l	< 5	ISO17025	< 5				
1,1,2,2-Tetrachloroethane	ug/l	< 10	ISO17025	< 10				
1,2,3-Trichloropropane	ug/l	< 5	ISO17025	< 5				
n-Propylbenzene	ug/l	< 5	ISO17025	< 5				
Bromobenzene	ug/l	< 5	ISO17025	< 5				
2-Chlorotoluene	ug/l	< 5	ISO17025	< 5				
1,3,5-Trimethylbenzene	ug/l	< 5	ISO17025	< 5				
4-Chlorotoluene	ug/l	< 5	ISO17025	< 5				
tert-Butylbenzene	ug/l	< 5	ISO17025	< 5				
1,2,4-Trimethylbenzene	ug/l	< 5	ISO17025	< 5				
sec-Butylbenzene	ug/l	< 5	ISO17025	< 5				
p-Isopropyltoluene	ug/l	< 5	ISO17025	< 5				
1,3-Dichlorobenzene	ug/l	< 5	ISO17025	< 5				
1,4-Dichlorobenzene	ug/l	< 5	ISO17025	< 5				
n-Butylbenzene	ug/l	< 5	ISO17025	< 5				
1,2-Dichlorobenzene	ug/l	< 5	ISO17025	< 5				
1,2-Dibromo-3-chloropropane	ug/l	< 10	ISO17025	< 10				
Hexachlorobutadiene	ug/l	< 5	ISO17025	< 5				

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Water Analysis Certificate - Volatile Organic Compounds TIC (VOC)		
QTS Environmental Report No: 14-26770	**Date Sampled**	None Supplied
Soil Consultants Ltd	**Time Sampled**	None Supplied
Site Reference: Bedford Avenue	**TP / BH No**	BH2
Project / Job Ref: 9661	**Additional Refs**	W1
Order No: None Supplied	**Depth (m)**	None Supplied
Reporting Date: 27/11/2014	**QTSE Sample No**	126661

Compound No	Compound Name	% Match	Units	RL	Estimated Concentration
1	N/a	N/a	µg/l	< 5	< 5
2	N/a	N/a	µg/l	< 5	< 5
3	N/a	N/a	µg/l	< 5	< 5
4	N/a	N/a	µg/l	< 5	< 5
5	N/a	N/a	µg/l	< 5	< 5

There were no / other compounds identified with a match of >90%

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Water Analysis Certificate - Semi Volatile Organic Compounds (SVOC)						
QTS Environmental Report No: 14-26770	**Date Sampled**	None Supplied				
Soil Consultants Ltd	**Time Sampled**	None Supplied				
Site Reference: Bedford Avenue	**TP / BH No**	BH2				
Project / Job Ref: 9661	**Additional Refs**	W1				
Order No: None Supplied	**Depth (m)**	None Supplied				
Reporting Date: 27/11/2014	**QTSE Sample No**	126661				

Determinand	**Unit**	**RL**	**Accreditation**					
Phenol	ug/l	< 0.1	NONE	< 0.1				
1,2,4-Trichlorobenzene	ug/l	< 0.1	NONE	< 0.1				
2-Nitrophenol	ug/l	< 0.1	NONE	< 0.1				
Nitrobenzene	ug/l	< 0.1	NONE	< 0.1				
0-Cresol	ug/l	< 0.1	NONE	< 0.1				
bis(2-chloroethoxy)methane	ug/l	< 0.1	NONE	< 0.1				
bis(2-chloroethyl)ether	ug/l	< 0.1	NONE	< 0.1				
2,4-Dichlorophenol	ug/l	< 0.1	NONE	< 0.1				
2-Chlorophenol	ug/l	< 0.1	NONE	< 0.1				
1,3-Dichlorobenzene	ug/l	< 0.1	NONE	< 0.1				
1,4-Dichlorobenzene	ug/l	< 0.1	NONE	< 0.1				
1,2-Dichlorobenzene	ug/l	< 0.1	NONE	< 0.1				
2,4-Dimethylphenol	ug/l	< 0.1	NONE	< 0.1				
Isophorone	ug/l	< 0.1	NONE	< 0.1				
Hexachloroethane	ug/l	< 0.1	NONE	< 0.1				
p-Cresol	ug/l	< 0.1	NONE	< 0.1				
2,4,6-Trichlorophenol	ug/l	< 0.1	NONE	< 0.1				
2,4,5-Trichlorophenol	ug/l	< 0.1	NONE	< 0.1				
2-Nitroaniline	ug/l	< 0.1	NONE	< 0.1				
4-Chloro-3-methylphenol	ug/l	< 0.1	NONE	< 0.1				
2-Methylnaphthalene	ug/l	< 0.1	NONE	< 0.1				
Hexachlorocyclopentadiene	ug/l	< 0.1	NONE	< 0.1				
Hexachlorobutadiene	ug/l	< 0.1	NONE	< 0.1				
2,6-Dinitrotoluene	ug/l	< 0.1	NONE	< 0.1				
Dimethyl phthalate	ug/l	< 0.1	NONE	< 0.1				
2-Chloronaphthalene	ug/l	< 0.1	NONE	< 0.1				
4-Chloroanaline	ug/l	< 0.1	NONE	< 0.1				
4-Nitrophenol	ug/l	< 0.1	NONE	< 0.1				
4-Chlorophenyl phenyl ether	ug/l	< 0.1	NONE	< 0.1				
3-Nitroaniline	ug/l	< 0.1	NONE	< 0.1				
4-Nitroaniline	ug/l	< 0.1	NONE	< 0.1				
4-Bromophenyl phenyl ether	ug/l	< 0.1	NONE	< 0.1				
Hexachlorobenzene	ug/l	< 0.1	NONE	< 0.1				
2,4-Dinitrotoluene	ug/l	< 0.1	NONE	< 0.1				
Diethyl phthalate	ug/l	< 0.1	NONE	< 0.1				
Dibenzofuran	ug/l	< 0.1	NONE	< 0.1				
Azobenzene	ug/l	< 0.1	NONE	< 0.1				
Dibutyl phthalate	ug/l	< 0.1	NONE	< 0.1				
Carbazole	ug/l	< 0.1	NONE	< 0.1				
bis(2-ethylhexyl)phthalate	ug/l	< 0.1	NONE	< 0.1				
Benzyl butyl phthalate	ug/l	< 0.1	NONE	< 0.1				
Di-n-octyl phthalate	ug/l	< 0.1	NONE	< 0.1				

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Water Analysis Certificate - Semi Volatile Organic Compounds TIC (SVOC)		
QTS Environmental Report No: 14-26770	**Date Sampled**	None Supplied
Soil Consultants Ltd	**Time Sampled**	None Supplied
Site Reference: Bedford Avenue	**TP / BH No**	BH2
Project / Job Ref: 9661	**Additional Refs**	W1
Order No: None Supplied	**Depth (m)**	None Supplied
Reporting Date: 27/11/2014	**QTSE Sample No**	126661

Compound No	Compound Name	% Match	Units	RL	Estimated Concentration
1	N/a	N/a	µg/l	< 0.1	< 0.1
2	N/a	N/a	µg/l	< 0.1	< 0.1
3	N/a	N/a	µg/l	< 0.1	< 0.1
4	N/a	N/a	µg/l	< 0.1	< 0.1
5	N/a	N/a	µg/l	< 0.1	< 0.1

There were no / other compounds identified with a match of >90%

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Water Analysis Certificate - PCB (7 Congeners)						
QTS Environmental Report No: 14-26770	**Date Sampled**	None Supplied				
Soil Consultants Ltd	**Time Sampled**	None Supplied				
Site Reference: Bedford Avenue	**TP / BH No**	BH2				
Project / Job Ref: 9661	**Additional Refs**	W1				
Order No: None Supplied	**Depth (m)**	None Supplied				
Reporting Date: 27/11/2014	**QTSE Sample No**	126661				

Determinand	**Unit**	**RL**	**Accreditation**					
PCB Congener 28	ug/l	< 0.1	NONE	< 0.1				
PCB Congener 52	ug/l	< 0.1	NONE	< 0.1				
PCB Congener 101	ug/l	< 0.1	NONE	< 0.1				
PCB Congener 118	ug/l	< 0.1	NONE	< 0.1				
PCB Congener 138	ug/l	< 0.1	NONE	< 0.1				
PCB Congener 153	ug/l	< 0.1	NONE	< 0.1				
PCB Congener 180	ug/l	< 0.1	NONE	< 0.1				
Total PCB (7 Congeners)	ug/l	< 0.7	NONE	< 0.7				

Water Analysis Certificate - Speciated Phenols						
QTS Environmental Report No: 14-26770	**Date Sampled**	None Supplied				
Soil Consultants Ltd	**Time Sampled**	None Supplied				
Site Reference: Bedford Avenue	**TP / BH No**	BH2				
Project / Job Ref: 9661	**Additional Refs**	W1				
Order No: None Supplied	**Depth (m)**	None Supplied				
Reporting Date: 27/11/2014	**QTSE Sample No**	126661				

Determinand	**Unit**	**RL**	**Accreditation**					
2, 3, 5-trimethylphenol	ug/l	< 0.1	NONE	< 0.1				
2, 3, 6-trimethylphenol	ug/l	< 0.1	NONE	< 0.1				
2, 3-xylenol	ug/l	< 0.1	NONE	< 0.1				
2, 4, 6-trimethylphenol	ug/l	< 0.1	NONE	< 0.1				
2, 4-xylenol	ug/l	< 0.1	NONE	< 0.1				
2, 5-xylenol	ug/l	< 0.1	NONE	< 0.1				
2, 6-xylenol	ug/l	< 0.1	NONE	< 0.1				
2-ethylphenol	ug/l	< 0.1	NONE	< 0.1				
2-isopropylphenol	ug/l	< 0.1	NONE	< 0.1				
3, 4, 5-trimethylphenol	ug/l	< 0.1	NONE	< 0.1				
3, 4-xylenol	ug/l	< 0.1	NONE	< 0.1				
3, 5-xylenol	ug/l	< 0.1	NONE	< 0.1				
3-ethylphenol	ug/l	< 0.1	NONE	< 0.1				
3-isopropylphenol	ug/l	< 0.1	NONE	< 0.1				
4-ethylphenol	ug/l	< 0.1	NONE	< 0.1				
4-isopropylphenol	ug/l	< 0.1	NONE	< 0.1				
m-cresol (3-methylphenol)	ug/l	< 0.1	NONE	< 0.1				
o-cresol (2-methylphenol)	ug/l	< 0.1	NONE	< 0.1				
p-cresol (4-methylphenol)	ug/l	< 0.1	NONE	< 0.1				
phenol	ug/l	< 0.1	NONE	< 0.1				

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Soil Analysis Certificate - Methodology & Miscellaneous Information
QTS Environmental Report No: 14-26770
Soil Consultants Ltd
Site Reference: Bedford Avenue
Project / Job Ref: 9661
Order No: None Supplied
Reporting Date: 27/11/2014

Matrix	Analysed On	Determinand	Brief Method Description	Method No
Water	UF	Alkalinity	Determination of alkalinity by titration against hydrochloric acid using bromocresol green as the end point	E103
Water	UF	BTEX	Determination of BTEX by headspace GC-MS	E101
Water	F	Cations	Determination of cations by filtration followed by ICP-MS	E102
Water	UF	Chemical Oxygen Demand (COD)	Determination using a COD reactor followed by colorimetry	E112
Water	F	Chloride	Determination of chloride by filtration & analysed by ion chromatography	E109
Water	F	Chromium - Hexavalent	Determination of hexavalent chromium by acidification, addition of 1,5 diphenylcarbazide followed by c	E116
Water	UF	Cyanide - Complex	Determination of complex cyanide by distillation followed by colorimetry	E115
Water	UF	Cyanide - Free	Determination of free cyanide by distillation followed by colorimetry	E115
Water	UF	Cyanide - Total	Determination of total cyanide by distillation followed by colorimetry	E115
Water	UF	Cyclohexane Extractable Matter (CEM)	Gravimetrically determined through liquid:liquid extraction with cyclohexane	E111
Water	F	Diesel Range Organics (C10 - C24)	Determination of liquid:liquid extraction with hexane followed by GI-FID	E104
Water	F	Dissolved Organic Content (DOC)	Determination of DOC by filtration followed by low heat with persulphate addition followed by IR detect	E110
Water	UF	Electrical Conductivity	Determination of electrical conductivity by electrometric measurement	E123
Water	F	EPH (C10 – C40)	Determination of liquid:liquid extraction with hexane followed by GI-FID	E104
Water	F	EPH TEXAS	Determination of liquid:liquid extraction with hexane followed by GI-FID	E104
Water	F	Fluoride	Determination of Fluoride by filtration & analysed by ion chromatography	E109
Water	F	Hardness	Determination of Ca and Mg by ICP-MS followed by calculation	E102
Leachate	F	Leachate Preparation - NRA	Based on National Rivers Authority leaching test 1994	E301
Leachate	F	Leachate Preparation - WAC	Based on BS EN 12457 Pt1, 2, 3	E302
Water	F	Metals	Determination of metals by filtration followed by ICP-MS	E102
Water	F	Mineral Oil (C10 - C40)	Determination of liquid:liquid extraction with hexane followed by GI-FID	E104
Water	F	Nitrate	Determination of nitrate by filtration & analysed by ion chromatography	E109
Water	UF	Monohydric Phenol	Determination of phenols by distillation followed by colorimetry	E121
Water	F	PAH - Speciated (EPA 16)	Determination of PAH compounds by concentration through SPE cartridge, collection in dichloromethane followed by GC-MS	E105
Water	F	PCB - 7 Congeners	Determination of PCB compounds by concentration through SPE cartridge, collection in dichloromethane	E108
Water	UF	Petroleum Ether Extract (PEE)	Gravimetrically determined through liquid:liquid extraction with petroleum ether	E111
Water	UF	pH	Determination of pH by electrometric measurement	E107
Water	F	Phosphate	Determination of phosphate by filtration & analysed by ion chromatography	E109
Water	UF	Redox Potential	Determination of redox potential by electrometric measurement	E113
Water	F	Sulphate (as SO4)	Determination of sulphate by filtration & analysed by ion chromatography	E109
Water	UF	Sulphide	Determination of sulphide by distillation followed by colorimetry	E118
Water	F	SVOC	Determination of semi-volatile organic compounds by concentration through SPE cartridge, collection in dichloromethane followed by GC-MS	E106
Water	UF	Toluene Extractable Matter (TEM)	Gravimetrically determined through liquid:liquid extraction with toluene	E111
Water	UF	Total Organic Carbon (TOC)	Low heat with persulphate addition followed by IR detection	E110
Water	F	TPH CWG	Determination of liquid:liquid extraction with hexane, fractionating with SPE followed by GC-FID	E104
Water	F	TPH LQM	Determination of liquid:liquid extraction with hexane, fractionating with SPE followed by GC-FID	E104
Water	UF	VOCs	Determination of volatile organic compounds by headspace GC-MS	E101
Water	UF	VPH (C6 - C10)	Determination of hydrocarbons C6-C10 by headspace GC-MS	E101

Key

F Filtered
UF Unfiltered

Appendix C Risk Rating Matrix

Table H.1: Risk rating for contaminated land qualitative risk assessment

Level of Severity	Likelihood		
	Most Likely	**Reasonably Foreseeable**	**Unlikely**
Acute harm or severe chronic harm. Direct pollution of sensitive water receptors or serious pollution of other water bodies.	High	High	Low
Harm from long-term exposure. Slight pollution of sensitive receptors or pollution of other water bodies.	Medium	Medium	Low
No significant harm in either short or long term. No pollution of water that is likely to affect sensitive receptors. No more than slight pollution of other water bodies.	Low	Low	Low

Appendix D Environmental Receptors

The Contaminated Land Statutory Guidance has a four category system that considers harm to human health, controlled waters, flora and fauna, property, livestock and crops. The Categories are broadly defined as follows:

1 Contaminated Land – similar to land where it is known that significant harm has been caused or significant harm is being caused

2 Contaminated Land – no significant harm being caused but there is a significant possibility for significant harm to be caused in the future

3 Not Contaminated Land – there may be harm being caused but no significant possibility for significant harm to be caused in the future

4 Not Contaminated Land – no pollutant linkage, normal levels of contaminants and no significant harm being caused and no significant possibility for significant harm to be caused in the future.

Table I.1: Significant pollution to controlled waters

Pollution of controlled waters

Under Section 78A(9) of Part 2A the term “pollution of controlled waters means the entry into controlled waters of any poisonous, noxious or polluting matter or any solid waste matter. The term “controlled waters” in relation to England has the same meaning as in Part 3 of the Water Resources Act 1991, except that “ground waters” does not include water contained in underground strata but above the saturation zones. (Paragraph 4.36)

Given that the Part 2A regime seeks to identify and deal with significant pollution (rather than lesser levels of pollution), the local authority should seek to focus on pollution which: (i) may be harmful to human health or the quality of aquatic ecosystems or terrestrial ecosystems directly depending on aquatic ecosystems; (ii) which may result in damage to material property; or (iii) which may impair or interfere with amenities and other legitimate uses of the environment. (Paragraph 4.37)

Significant pollution of controlled waters

Paragraph 4.38 states that “The following types of pollution should be considered to constitute significant pollution of controlled waters:

(a) Pollution equivalent to “environmental damage” to surface water or groundwater as defined by The Environmental Damage (Prevention and Remediation) Regulations 2009, but which cannot be dealt with under those Regulations.

(b) Inputs resulting in deterioration of the quality of water abstracted, or intended to be used in the future, for human consumption such that additional treatment would be required to enable that use.

(c) A breach of a statutory surface water Environment Quality Standard, either directly or via a groundwater pathway.

(d) Input of a substance into groundwater resulting in a significant and sustained upward trend in concentration of contaminants (as defined in Article 2(3) of the Groundwater Daughter Directive (2006/118/EC)5)”.

Paragraph 4.39 states that “In some circumstances, the local authority may consider that the following types of pollution may constitute significant pollution: (a) significant concentrations6 of hazardous substances or non-hazardous pollutants in groundwater; or (b) significant concentrations of priority hazardous substances, priority substances or other specific polluting substances in surface water; at an appropriate, risk based compliance point. The local authority should only conclude that pollution is significant if it considers that treating the land as contaminated land would be in accordance with the broad objectives of the regime as described in Section 1 (of the Contaminated Land Statutory Guidance). This would normally mean that the authority should conclude that less serious forms of pollution are not significant. In such cases the authority should consult the Environment Agency”.

The following types of circumstance should not be considered to be contaminated land on water pollution grounds:

(a) The fact that substances are merely entering water and none of the conditions for considering that significant pollution is being caused set out in paragraphs 4.38 and 4.39 above are being met.

(b) The fact that land is causing a discharge that is not discernible at a location immediately downstream or down-gradient of the land (when compared to upstream or up-gradient concentrations).

(c) Substances entering water in compliance with a discharge authorised under the Environmental Permitting Regulations.

Significant pollution of controlled waters is being caused

In deciding whether significant pollution of controlled waters is being caused, the local authority should consider that this test is only met where it is satisfied that the substances in question are continuing to enter controlled waters; or that they have already entered the waters and are likely to do so again in such a manner that past and likely future entry in effect constitutes ongoing pollution. For these purposes, the local authority should:

(a) Regard substances as having entered controlled waters where they are dissolved or suspended in those waters, or (if they are immiscible with water) they have direct contact with those waters on or beneath the surface of the water.

(b) Take the term “continuing to enter” to mean any measurable entry of the substance(s) into controlled waters additional to any which has already occurred.

(c) Take the term “likely to do so again” to mean more likely than not to occur again.

Land should not be determined as contaminated land on grounds that significant pollution of controlled waters is being caused where: (a) the relevant substance(s) are already present in controlled waters; (b) entry into controlled waters of the substance(s) from land has ceased; and (c) it is not likely that further entry will take place.

Significant Possibility of Significant Pollution of Controlled Waters

In deciding whether or not a significant possibility of significant pollution of controlled waters exists, the local authority should first understand the possibility of significant pollution of controlled waters posed by the land, and the levels of certainty/uncertainty attached to that understanding, before it goes on to decide whether or not that possibility is significant. The term “possibility of significant pollution of controlled waters” means the estimated likelihood that significant pollution of controlled waters might occur. In assessing the possibility of significant pollution of controlled waters from land, the local authority should act in accordance with the advice on risk assessment in Section 3 and the guidance in this sub-section.

In deciding whether the possibility of significant pollution of controlled waters is significant the local authority should bear in mind that Part 2A makes the decision a positive legal test. In other words, for particular land to meet the test the authority needs reasonably to believe that there is a significant possibility of such pollution, rather than to demonstrate that there is not.

Before making its decision on whether a given possibility of significant pollution of controlled waters is significant, the local authority should consider:

(a) The estimated likelihood that the potential significant pollution of controlled waters would become manifest; the strength of evidence underlying the estimate; and the level of uncertainty underlying the estimate.

(b) The estimated impact of the potential significant pollution if it did occur. This should include consideration of whether the pollution would be likely to cause a breach of European water legislation, or make a major contribution to such a breach.

(c) The estimated timescale over which the significant pollution might become manifest.

(d) The authority’s initial estimate of whether remediation is feasible, and if so what it would involve and the extent to which it might provide a solution to the problem; how long it would take; what benefit it would be likely to bring; and whether the benefits would outweigh the costs and any impacts on local society or the environment from taking action

Reproduced from DEFRA (2012) Contaminated Land Statutory Guidance pursuant to section 78YA of the Environmental Protection Act 1990 as amended by Section 57 of the Environment Act 1995.

Table I.2: Significant harm to human health, ecological systems and property

Relevant types of receptor	**Significant harm**	**Significant possibility of significant harm**
Human beings	The following health effects should always be considered to constitute significant harm to human health: death; life threatening diseases (eg cancers); other diseases likely to have serious impacts on health; serious injury; birth defects; and impairment of reproductive functions. Other health effects may be considered by the local authority to constitute significant harm. For example, a wide range of conditions may or may not constitute significant harm (alone or in combination) including: physical injury; gastrointestinal disturbances; respiratory tract effects; cardio-vascular effects; central nervous system effects; skin ailments; effects on organs such as the liver or kidneys; or a wide range of other health impacts. In deciding whether or not a particular form of harm is significant harm, the local authority	The risk posed by one or more relevant contaminant linkage(s) relating to the land comprises: (a) The estimated likelihood that significant harm might occur to an identified receptor, taking account of the current use of the land in question. (b) The estimated impact if the significant harm did occur – i.e. the nature of the harm, the seriousness of the harm to any person who might suffer it, and (where relevant) the extent of the harm in terms of how many people might suffer it. In estimating the likelihood that a specific form of significant harm might occur the local authority should, among other things, consider: (a) The estimated probability that

Relevant types of receptor	Significant harm	Significant possibility of significant harm
	should consider the seriousness of the harm in question: including the impact on the health, and quality of life, of any person suffering the harm; and the scale of the harm. The authority should only conclude that harm is significant if it considers that treating the land as contaminated land would be in accordance with the broad objectives of the regime as described in Section 1 of the Contaminated Land Statutory Guidance.	the significant harm might occur: (i) if the land continues to be used as it is currently being used; and (ii) where relevant, if the land were to be used in a different way (or ways) in the future having regard to the guidance on "current use" in Section 3 of the Contaminated Land Statutory Guidance. (b) The strength of evidence underlying the risk estimate. It should also consider the key assumptions on which the estimate of likelihood is based, and the level of uncertainty underlying the estimate.
Any ecological system, or living organism forming part of such a system, within a location which is: • a site of special scientific interest (under section 28 of the Wildlife and Countryside Act (WCA) 1981 (as amended) and Part 4 of the Natural Environment and Rural Communitites Act 2006 (as amended)); • a national nature reserve (under Section 35 of the WCA 1981 (as amended)); • a marine nature reserve (under Section 36 of the WCA 1981 (as amended)); • an area of special protection for birds (under Section 3 of the WCA 1981 (as amended)); • a "European site" within the meaning of regulation 8 of the Conservation of Habitats and Species Regulations 2010 (as amended); • any habitat or site afforded policy protection under Section 11 of The National Planning Policy Framework (NPPF) on conserving and enhancing the natural environment (i.e. possible Special Areas of Conservation, potential Special	The following types of harm should be considered to be significant harm: • harm which results in an irreversible adverse change, or in some other substantial adverse change, in the functioning of the ecological system within any substantial part of that location; or • harm which significantly affects any species of special interest within that location and which endangers the long-term maintenance of the population of that species at that location. In the case of European sites, harm should also be considered to be significant harm if it endangers the favourable conservation status of natural habitats at such locations or species typically found there. In deciding what constitutes such harm, the local authority should have regard to the advice of Natural England and to the requirements of the Conservation of Habitats and Species Regulations 2010 (as amended).	Conditions would exist for considering that a significant possibility of significant harm exists to a relevant ecological receptor where the local authority considers that: • significant harm of that description is more likely than not to result from the contaminant linkage in question; or • there is a reasonable possibility of significant harm of that description being caused, and if that harm were to occur, it would result in such a degree of damage to features of special interest at the location in question that they would be beyond any practicable possibility of restoration. Any assessment made for these purposes should take into account relevant information for that type of contaminant linkage, particularly in relation to the ecotoxicological effects of the contaminant.

Relevant types of receptor	Significant harm	Significant possibility of significant harm
Protection Areas and listed or proposed Ramsar sites); or • any nature reserve established under Section 21 of the National Parks and Access to the Countryside Act 1949.		
Property in the form of: • crops, including timber • produce grown domestically, or on allotments, for consumption • livestock • other owned or domesticated animals; • wild animals which are the subject of shooting or fishing rights.	For crops, a substantial diminution in yield or other substantial loss in their value resulting from death, disease or other physical damage. For domestic pets, death, serious disease or serious physical damage. For other property in this category, a substantial loss in its value resulting from death, disease or other serious physical damage. The local authority should regard a substantial loss in value as occurring only when a substantial proportion of the animals or crops are dead or otherwise no longer fit for their intended purpose. Food should be regarded as being no longer fit for purpose when it fails to comply with the provisions of the Food Safety Act 1990. Where a diminution in yield or loss in value is caused by a pollutant linkage, a 20% diminution or loss should be regarded as a benchmark for what constitutes a substantial diminution or loss. In the Guidance states that this description of significant harm is referred to as an “animal or crop effect”.	Conditions would exist for considering that a significant possibility of significant harm exists to the relevant types of receptor where the local authority considers that significant harm is more likely than not to result from the contaminant linkage in question, taking into account relevant information for that type of contaminant linkage, particularly in relation to the ecotoxicological effects of the contaminant.
Property in the form of buildings. For this purpose 'building' means any structure or erection and any part of a building, including any part below ground level, but does not include plant or machinery comprised in a building, or buried services such as sewers, water pipes or electricity cables.	Structural failure, substantial damage or substantial interference with any right of occupation. The local authority should regard substantial damage or substantial interference as occurring when any part of the building ceases to be capable of being used for the purpose for which it is or was intended. In the case of a scheduled Ancient Monument, substantial damage should be regarded as occurring when the damage significantly impairs the historic, architectural, traditional, artistic or archaeological interest by reason of which the monument was scheduled.	Conditions would exist for considering that a significant possibility of significant harm exists to the relevant types of receptor where the local authority considers that significant harm is more likely than not to result from the contaminant linkage in question during the expected economic life of the building (or in the case of a scheduled Ancient Monument the foreseeable future), taking into account relevant information for that type of contaminant linkage.

Relevant types of receptor	Significant harm	Significant possibility of significant harm
	The Guidance states that this description of significant harm is referred to as a 'building effect'.	

Reproduced from DEFRA (2012) Contaminated Land Statutory Guidance pursuant to section 78YA of the Environmental Protection Act 1990 as amended by Section 57 of the Environment Act 1995.

Appendix E Generic Assessment Criteria

Human Health Generic Assessment Criteria

Background

In order to be able to make inference on whether the results obtained during the site investigation (e.g. chemical concentrations in soils, waters and gas) point to the presence of a potential hazard to human health, it is necessary to distinguish between the results, reflecting background and/or insignificantly elevated levels of contamination (i.e. with negligible potential to cause harm or pollution) and the results with significantly elevated concentrations (i.e. with significant potential to cause harm or pollution).

The approach to risk assessment with respect to risks to human health from contaminated land in the UK is set out in the publication Model Procedures for the Management of Land Contamination (CLR11) Environment Agency (2004).

This sets out a tiered approach:

- Preliminary Risk Assessment (e.g. establishing potential pollutant linkages);
- Generic Quantitative Risk Assessment (GQRA) (e.g. comparison of site contaminant concentrations against generic standards and compliance criteria e.g. Soil Guideline Values (SGV) or other Generic Assessment Criteria including an assessment of risk using the source pathway target model); and
- Detailed Quantitative Risk Assessment (DQRA) (e.g. the comparison of contaminant concentrations against site specific assessment criteria).

Preliminary Risk Assessment

This typically encompasses a desk based generation of a conceptual model to establish the potential pollutant linkages associated with the site and any proposed development. Works would typically involve:

- Evaluation of the potential sources of contamination on the site and in the locality and from both a current and historical perspective
- Statutory Consultation;
- Evaluation of a sites geology, hydrology and hydrogeology;
- Site inspection;
- Additional pertinent information as necessary on a site by site basis.

Where works indicate the presence of a potential pollutant linkage further evaluation and potentially site investigation works are necessary to determine the significance of the linkage.

Generic Quantitative Risk Assessment (GQRA)

In August 2008 the Environment Agency (EA) and Department of Environment Food and Rural Affairs (DEFRA) announced the withdrawal of the Contaminated Land Reports CLR7 – 10, CLEA UK (beta) and existing SGV reports as they no-longer fully reflected the revised approach to human health risk assessment.

New partial guidance (in particular Science Reports SR2, SR3 and SR7) and new risk assessment tools (CLEA model version v1.04, v1.05 and currently v1.06) were published in 2009 and these allow environmental practitioners to derive generic and site specific Soil Assessment Criteria (GAC and SAC).

Soil Guideline Values (SGVs)

The EA and DEFRA updated the TOX reports and Soil Guideline Values (SGVs) to reflect the guidance documents published in 2009. SGVs for arsenic, cadmium, nickel, mercury, selenium, BTEX compounds (benzene, toluene, ethylbenzene and xylenes), dioxins, furans and dioxin like PCBs and phenol have been made available.

Since publishing the revised SGVs the CLEA model was updated to version v1.06. The Environment Agency has however confirmed that v1.05 has only a "minor effect on assessment criteria calculated using the CLEA software 1.04" and consequently the GACs derived are considered to remain valid. Environment Agency SGVs generated using v1.04 have also not been updated. Software version v1.06 is identical to v1.05 with some password protection enhancements that in no way affect the GAC values generated.

Owing to the scientific advances since 2009 and in particular toxicological research outputs, less significance is now placed on the SGVs in the hierarchy outlined below.

Category 4 Screening Levels (C4SLs)

Category 4 Screening Levels were generated by Contaminated Land: Applications in Real Environments (CL:AIRE) on behalf of DEFRA and made available to the public in April 2014. Category 4 Screening Levels were derived in response to policy changes outlined in the recently revised Statutory Guidance (SG) for Part 2A of the Environmental Protection Act 1990 (Part 2A). Part 2A was originally introduced to ensure that the risks from land contamination to human health, property and the environment are managed appropriately, with the revised SG being designed to address concerns regarding its real-world application. The revised SG presents a new four category system for classifying land under Part 2A, ranging from Category 4, where the level of risk posed is acceptably low, to Category 1, where the level of risk is clearly unacceptable.

The document SP1010: Development of Category 4 Screening Levels for Assessment of Land Affected by Contamination – Policy Companion Document (March 2014) states that:

The Impact Assessment that accompanied the revised Part 2A Statutory Guidance identified a potential role for new 'Category 4 Screening Levels' in providing a simple test for deciding when land is suitable for use and definitely not contaminated land. It was envisaged that these new screening levels would allow 'low-risk' land to be dismissed from the need for further risk assessment more quickly and easily and allow regulators to focus efforts on the highest-risk land. The C4SLs were proposed to be more pragmatic (whilst still strongly precautionary) compared to existing generic screening levels. It is anticipated that, where they exist, C4SLs will be used as generic screening criteria that can be used within a GQRA, albeit describing a higher level of risk than the currently or previously available SGVs.

Suitable For Use Screening Levels (S4USLs)

In January 2015, Land Quality Management (LQM) and the Chartered Institute of Environmental Health (CIEH) have published updated screening criteria that were derived in line with UK guidance on risk assessment (SR2 and SR3). The resultant screening criteria reflect the industries greater knowledge of the relevant toxicology and further consideration of exposure scenarios as set out in SP1010.

Waterman’s Generic Assessment Criteria (GACs)

Waterman have used the following hierarchy for the generic assessment of soils to evaluate Human Health.

- Published Category 4 Screening Values (C4SLs) derived by CL:AIRE on behalf of DEFRA; or in their absence;
- Suitable 4 Use Screening Levels (S4USLs) derived by LQM/CIEH; or in their absence;
- Published Soil Guideline Values (SGVs);
- GAC prepared in accordance with the CLEA v1.04 / v1.06 model by authoritative bodies (e.g. Contaminated Land Applications in Real Environments (CL:AIRE) 2009; and
- Waterman in-house GAC prepared in accordance with the CLEA V1.06 model and associated documents.

Tabulated values of the GACs used are presented overleaf. The references of the sources quoted in the table are:-

- Environment Agency, 2009. CLEA Software, version 1.06;
- DEFRA, Environment Agency, 2004. Model Procedures for the Management of Land Contamination, Contaminated Land Report 11;
- DEFRA, 2014, SP1010: Development of Category 4 Screening Levels for Assessment of Land Affected by Contamination – Policy Companion Document and appendices;
- LQM / CIEH, 2015. The LQM/CIEH S4ULs for Human Health Risk Assessment;
- Environment Agency, 2009. Human health toxicological assessment of contaminants in soil. Report SC050021/SR2;
- Environment Agency, 2009. Updated technical background to the CLEA model. Report SC050021/SR3;
- Environment Agency, 2008. Compilation of chemical data for priority organic pollutants for derivation of Soil Guideline Values. Report SC050021/SR7; and
- EIC / CL:AIRE, 2010. Soil generic assessment criteria for human health risk assessment.

Detailed Quantitative Risk Assessment (DQRA)

Detailed Quantitative Risk Assessments are undertaken on a site specific basis and full details of the alterations to the CLEA model and generic land use scenarios will be described within the specific reports.

Generic Quantitative Risk Assessment Criteria

Proposed End Use	units	Commercial			Source
Soil Organic Matter Content	**%**	**1**	**2.5**	**6**	
Arsenic	mg/kg	640	640	640	DEFRA C4SLs
Antimony	mg/kg	7500	7500	7500	CL:AIRE 2009
Barium	mg/kg	22000	22000	22000	CL:AIRE 2009
Beryllium	mg/kg	12	12	12	LQM S4ULs 2015
Boron (Water Soluble)	mg/kg	240000	240000	240000	LQM S4ULs 2015
Cadmium	mg/kg	410	410	410	DEFRA C4SLs
Chromium (Total)	mg/kg	8600	8600	8600	LQM S4ULs 2015
Chromium (VI)	mg/kg	49	49	49	DEFRA C4SLs
Copper	mg/kg	68000	68000	68000	LQM S4ULs 2015
Lead	mg/kg	2330	2330	2330	DEFRA C4SLs
Mercury	mg/kg	58	58	58	LQM S4ULs 2015
Molybdenum	mg/kg	17000	17000	17000	CL:AIRE 2009
Nickel	mg/kg	980	980	980	LQM S4ULs 2015
Selenium	mg/kg	12000	12000	12000	LQM S4ULs 2015
Vanadium*	mg/kg	9000	9000	9000	LQM S4ULs 2015
Zinc	mg/kg	730000	730000	730000	LQM S4ULs 2015
Cyanide (Free)	mg/kg	16000	16000	16000	Waterman GAC - CLEA v1.06
Complex Cyanide	mg/kg	430000	430000	430000	Waterman GAC - CLEA v1.06

Proposed End Use	units	Commercial			Source
Soil Organic Matter Content	%	1	2.5	6	
Thiocyanate	mg/kg	22000	22000	22000	Waterman GAC - CLEA v1.06
Aliphatic EC5 - EC6	mg/kg	3200	5900	12000	LQM S4ULs 2015
Aliphatic EC6 - EC8	mg/kg	7800	17000	40000	LQM S4ULs 2015
Aliphatic EC8-EC10	mg/kg	2000	4800	11000	LQM S4ULs 2015
Aliphatic EC10-EC12	mg/kg	9700	23000	47000	LQM S4ULs 2015
Aliphatic EC12-EC16	mg/kg	59000	8200	90000	LQM S4ULs 2015
Aliphatic EC16-EC35	mg/kg	1000000	1000000	1000000	LQM S4ULs 2015
Aliphatic EC35-EC44	mg/kg	1000000	1000000	1000000	LQM S4ULs 2015
Aromatic C5-C7	mg/kg	26000	46000	86000	LQM S4ULs 2015
Aromatic C7-C8	mg/kg	56000	110000	180000	LQM S4ULs 2015
Aromatic C8-C10	mg/kg	3500	8100	17000	LQM S4ULs 2015
Aromatic C10-C12	mg/kg	16000	28000	34000	LQM S4ULs 2015
Aromatic C12-C16	mg/kg	36000	37000	38000	LQM S4ULs 2015
Aromatic C16-C21	mg/kg	28000	28000	28000	LQM S4ULs 2015
Aromatic C21-C35	mg/kg	28000	28000	28000	LQM S4ULs 2015
Aromatic C35-C44	mg/kg	28000	28000	28000	LQM S4ULs 2015
Benzene	mg/kg	27	47	90	LQM S4ULs 2015
Toluene	mg/kg	56000	110000	180000	LQM S4ULs 2015
Ethyl Benzene	mg/kg	5700	13000	27000	LQM S4ULs 2015
Xylene - o	mg/kg	6200	14000	31000	LQM S4ULs 2015

Proposed End Use	**units**		**Commercial**		**Source**
Soil Organic Matter Content	**%**	**1**	**2.5**	**6**	
Xylene - m	mg/kg	6600	15000	33000	LQM S4ULs 2015
Xylene - p	mg/kg	5900	14000	30000	LQM S4ULs 2015
MTBE (Methyl tert-butyl ether)	mg/kg	7900	13000	24000	CL:AIRE 2009
Naphthalene	mg/kg	190	460	1100	LQM S4ULs 2015
Acenaphthylene	mg/kg	83000	97000	100000	LQM S4ULs 2015
Acenaphthene	mg/kg	84000	97000	100000	LQM S4ULs 2015
Fluorene	mg/kg	63000	68000	71000	LQM S4ULs 2015
Phenanthrene	mg/kg	22000	22000	23000	LQM S4ULs 2015
Anthracene	mg/kg	520000	540000	540000	LQM S4ULs 2015
Fluoranthene	mg/kg	23000	23000	23000	LQM S4ULs 2015
Pyrene	mg/kg	54000	54000	54000	LQM S4ULs 2015
Benzo(a)anthracene	mg/kg	170	170	180	LQM S4ULs 2015
Chrysene	mg/kg	350	350	350	LQM S4ULs 2015
Benzo(b)fluoranthene	mg/kg	44	44	45	LQM S4ULs 2015
Benzo(k)fluoranthene	mg/kg	1200	1200	1200	LQM S4ULs 2015
Benzo(a)pyrene	mg/kg	35	35	36	LQM S4ULs 2015
Indeno(1,2,3-cd)pyrene	mg/kg	500	510	510	LQM S4ULs 2015
Di-benzo(a.h.)anthracene	mg/kg	3.5	3.6	3.6	LQM S4ULs 2015
Benzo(g.h.i.) Perylene	mg/kg	3900	4000	4000	LQM S4ULs 2015
Phenol	mg/kg	760	1500	3200	LQM S4ULs 2015

Proposed End Use	units	Commercial			Source
Soil Organic Matter Content	**%**	**1**	**2.5**	**6**	
Pentachlorophenol (PCP)	mg/kg	400	400	400	LQM S4ULs 2015
1,1,2,2 Tetrachloroethane	mg/kg	270	550	1100	LQM S4ULs 2015
1,1,1,2 Tetrachloroethane	mg/kg	110	250	560	LQM S4ULs 2015
1,1,1 Trichloroethane	mg/kg	660	1300	3000	LQM S4ULs 2015
Trichloroethene	mg/kg	1.2	2.6	5.7	LQM S4ULs 2015
Tetrachloromethane (Carbon Tetrachloride)	mg/kg	2.9	6.3	14	LQM S4ULs 2015
1,2- Dichloroethane	mg/kg	0.67	0.97	1.7	LQM S4ULs 2015
Chloroethene (Vinyl chloride)	mg/kg	0.059	0.077	0.12	LQM S4ULs 2015
Trichloroethene	mg/kg	1.2	2.6	5.7	LQM S4ULs 2015
Tetrachloroethene	mg/kg	19	42	95	LQM S4ULs 2015
Trichloromethane (Chloroform)	mg/kg	99	170	350	LQM S4ULs 2015
Sum of PCDDs, PCDFs and dioxins like PCBs	mg/kg			240	CLEA SGVs 2009
Isopropylbenzene	mg/kg	1400	3300	7700	CL:AIRE 2009
Propylbenzene	mg/kg	4100	9700	21000	CL:AIRE 2009
Styrene	mg/kg	3300	6500	11000	CL:AIRE 2009
Bromobenzene	mg/kg	97	220	520	CL:AIRE 2009
1,1,2 Trichloroethane	mg/kg	94	190	400	CL:AIRE 2009
1,1-Dichloroethane	mg/kg	280	450	850	CL:AIRE 2009
1,1-Dichloroethene	mg/kg	26	46	92	CL:AIRE 2009

Proposed End Use	units	Commercial			Source
Soil Organic Matter Content	%	1	2.5	6	
1,2,4-Trimethylbenzene	mg/kg	42	99	220	CL:AIRE 2009
1,2-Dichloropropane	mg/kg	3.3	5.9	12	CL:AIRE 2009
2-Chloronaphthalene	mg/kg	390	960	2200	CL:AIRE 2009
Bromodichloromethane	mg/kg	2.1	3.7	7.6	CL:AIRE 2009
Bromoform	mg/kg	760	1500	3100	CL:AIRE 2009
Chloroethane	mg/kg	960	1300	2100	CL:AIRE 2009
Chloromethane	mg/kg	1	1.2	1.6	CL:AIRE 2009
Cis 1,2 Dichloroethene	mg/kg	14	24	47	CL:AIRE 2009
Dichloromethane	mg/kg	270	360	560	CL:AIRE 2009
Hexachloroethane	mg/kg	22	53	120	CL:AIRE 2009
Trans 1,2 Dichloroethene	mg/kg	22	40	81	CL:AIRE 2009
Bis (2-ethylhexyl) phthalate	mg/kg	85000	86000	86000	CL:AIRE 2009
Butyl benzyl phthalate	mg/kg	940000	940000	950000	CL:AIRE 2009
Diethyl Phthalate	mg/kg	150000	220000	290000	CL:AIRE 2009
Di-n-butyl phthalate	mg/kg	15000	15000	15000	CL:AIRE 2009
Di-n-octyl phthalate	mg/kg	89000	89000	89000	CL:AIRE 2009
Biphenyl	mg/kg	18000	33000	48000	CL:AIRE 2009
2,4-Dinitrotoluene	mg/kg	3700	3700	3800	CL:AIRE 2009
2,6-Dinitrotoluene	mg/kg	1900	1900	1900	CL:AIRE 2009
Tributyl tin oxide	mg/kg	130	180	200	CL:AIRE 2009

Soil Contamination – Risk of Harm to Property

Structures and Underground Services

Buried Concrete

BRE Special Digest 1 (2005), 3rd Edition, entitled *Concrete in aggressive ground*, provides guidance on the specification for concrete for installation in natural ground and in brownfield locations. The procedures given for the ground assessment and concrete specification cover the fairly common occurrences of sulfates, sulfides and acids, and the more rarely occurring aggressive carbon dioxide found in some ground and surface waters, which affects concrete foundations and sub-structures. It gives procedures for specification of concrete and applies to both buildings and civil engineering construction.

Water Supply Pipes

Guidance is provided in the UK Water Industry Research (UKWIR) report entitled *"Guidance for the Selection of Water Supply Pipes to be used in Brownfield Sites"* Report Ref. No. 10/WM/03/21, 2010.

Guidance is provided in the November 2010 Q&A Update and the Questions and Answers Sheet dated 4 May 2011 included at the back of the UKWIR report. Item 3 has been reproduced here:

Item	Question	Answer
3	Following the flow chart in Figure 1.1, **would it be acceptable to not undertake a site investigation and specify the use of barrier pipes** (these seem to be suitable for all conditions)? Would it be acceptable to adopt the blanket approach of always using barrier pipes at Brownfield sites, negating the need for a desk study or intrusive investigation?	The UKWIR project steering group decided that barrier pipes would provide sufficient protection for the supply of drinking water in all Brownfield site conditions. It is therefore reasonable to expect that water companies will accept the use of barrier pipe in all situations as a blanket approach

Soil Contamination – Risk of Combustion

The combustibility of soils is a complex function of soil type, energy content, and availability of oxygen. The Building Research Establishment (BRE) has published guidance based on Calorific Value (i.e. energy content, alone), namely *IP 2/87, Fire and explosion hazards associated with the redevelopment of contaminated land*. This document provides a level below which combustibility is unlikely (2MJ/kg) and a level above which combustibility is likely (10MJ/kg). In the range between these two values combustibility is uncertain. Therefore, where the lower value is exceeded, the other key factors mentioned above need to be considered.

Soil Contamination – Risk of Harm to Vegetation

Where there is topsoil present on Site and it is being considered for reuse in landscaped areas then it needs to be assessed for its suitability for use by an appropriately qualified specialist. Topsoil can be both naturally-occurring and manufactured. The requirements for topsoil that is to be reused on site are specified in BS3882:2007 and cover a range of properties including texture, organic matter content, grading, pH, nutrients and phytotoxic contaminants. The specification for phytotoxic contaminants is reproduced in the table below:

Phytotoxic Contaminants (by soil pH) for Topsoil

Contaminant*	**pH** **<6**	**6.0 to 7.0**	**>7**
Zinc (Nitric acid extractable**)	<200mg/kg	<200mg/kg	<300mg/kg
Copper (Nitric acid extractable**)	<100mg/kg	<135mg/kg	<200mg/kg
Nickel (Nitric acid extractable**)	<60mg/kg	<75mg/kg	<110mg.kg

Footnotes: * The lower of the Generic Assessment Criteria for chemical contaminants (human health and the environment) and phytotoxicity shall be used for topsoil

** The method of testing is given in Annex D to BS3882:2007 Specification for topsoil and requirements for use.

The risk to human health and the environment needs to be considered as well as phytotoxicity and this will be carried out using the Generic Assessment Criteria selected for these risks as described elsewhere in this appendix and this report.

In order to assess the suitability of topsoil to be reused the full range of testing specified needs to be carried out and assessed by an appropriately qualified specialist.

Controlled Waters Generic Assessment Criteria

The Screening Values adopted by Waterman for ground and surface water quality have been selected on the basis of the water quality standards that apply at the controlled water receptor considered to be at potential risk of harm. Where the receptor is to be assessed for potential harm to aquatic life then the Environmental Quality Standards (EQS) for List 1 and List 2 dangerous substances (EC Dangerous Substances Directive (76/464/EEC)) will be used. Where the receptor is to be assessed for potential harm with respect to use as a drinking water resource then the Water Supply (Water Quality) Regulations 1989 and 2000 as amended will be used. Where the receptor is to be used by aquatic life and for drinking water purposes both sets of criteria will be used. The standards for the substances tested for in this investigation are provided in Table D3 and D4 below.

Environmental Quality Standards

Environmental Quality Standards (EQS) annual average		**Freshwater**
pH (Acid)		6.0
pH (Alkaline)		9.0
Arsenic	µg/l	50
Cadmium	µg/l	5
Chromium	µg/l	5 – 250(1)
Lead	µg/l	4 -250(1)
Mercury	µg/l	1
Boron	µg/l	2000
Copper	µg/l	1 - 28(1)
Nickel	µg/l	50 - 200(1)
Zinc	µg/l	75 - 500(1)
Tetrachloromethane (PCM)	µg/l	12
Trichloroethene (TCE)	µg/l	10
Tetrachloroethene (PCE)	µg/l	10

Environmental Quality Standards (EQS) annual average		Freshwater
Benzene	µg/l	30
Toluene	µg/l	50
Xylene	µg/l	30

Footnotes:
NV – No value
(1) – Dependant on Hardness (See DoE circular 7/89).

UK Drinking Water Supply Standards

Water Supply (Water Quality) Regulations 1989 and 2000- as amended		
pH (Acid)		5.5
pH (Alkaline)		9.5
Arsenic	µg/l	10
Barium	µg/l	1000
Cadmium	µg/l	5
Chromium	µg/l	50
Lead	µg/l	25 (Reducing to 10 in 2013)
Mercury	µg/l	1
Selenium	µg/l	10
Boron	µg/l	1000
Copper	µg/l	2000
Nickel	µg/l	20
Zinc	µg/l	5000
Sulphate	mg/l	250
Total/Complex Cyanide	µg/l	50
Ammonium (NH4+)	µg/l	500
Nitrate (as $N0_3$)	mg/l	50
Hydrocarbons (dissolved/emulsions)	µg/l	10
Polyaromatic Hydrocarbons (PAH)	µg/l	0.1
Benzo(a)pyrene	µg/l	0.01
Phenol	µg/l	0.5
Tetrachloromethane	µg/l	3
Trichloroethene (TCE)	µg/l	10 (combined total)
Tetrachloroethene (PCE)	µg/l	3
Benzene	µg/l	1
Ethyl Benzene	µg/l	NV
Toluene	µg/l	NV
Xylene	µg/l	NV
EU Surface Water Directive (75/440/EEC) - Class A1 – only		

Water Supply (Water Quality) Regulations 1989 and 2000- as amended		
simple treatment required.		
Sulphide	mg/l	*150*

Ground Gas and Volatile Organic Compounds Generic Assessment Criteria

Ground Gas

The Building Regulations 2000 Approved Document C (2004 Edition) require that methane and other gases from the ground are considered on a risk assessment basis. Methane and other gases from the ground are defined in this document as *"hazardous soil gases which originate from waste deposited in landfill sites or are generated naturally"*. Ground gas can also be generated by fill materials present on sites that are not classed as landfills. Therefore a preliminary ground gas risk assessment should consider the potential for methane or other gases to be present. This includes identification of the potential sources on or near to the site that could produce methane or other ground gas.

The most common gases assessed with respect to development are methane and carbon dioxide. Methane forms a potentially explosive mixture when mixed with air within certain concentration limits, known as the 'explosive range'. The Lower Explosive Limit (LEL) for methane is 5%. Carbon dioxide (CO_2) is a dense gas, capable of accumulating in confined spaces such as basements, causing a potential asphyxiation hazard. The Occupational Exposure Limit (OEL) for a short-term exposure to carbon dioxide is 1.5% over a 15 minute period. Both methane and carbon dioxide when present at high concentrations can act as simple asphyxiants by reducing the oxygen content by dilution.

Reference in the Building Regulations is made to guidance documents produced by a variety of organisations, primarily those produced by the Construction Industry Research and Information Association (CIRIA). These include the following documents:

- CIRIA Report 149 Protecting development from methane, 1995
- CIRIA Report 131 The measurement of methane and other gases from the ground, 1993.
- CIRIA Report 150 Methane investigation strategies, 1995
- CIRIA Report 151 Interpreting measurements of gas in the ground, 1995
- CIRIA Report 152 Risk assessment for methane and other gases from the ground, 1995

In addition guidance is provided in the BRE document 'Construction of new buildings on gas-contaminated land (BRE Report BR212)'.

CIRIA, Report 131, 1993, suggests that there are no fixed rules for safe gas concentrations on a site since this risk is dependent on a number of factors that include gas emission rate from the ground and the potential for gas to enter into structures.

The Building Regulations relate to domestic dwellings. However, for non-domestic dwellings the same principle of risk assessment applies.

The latest guidance document is provided by CIRIA Report C665, *"Assessing risks posed by hazardous ground gases to buildings"*, 2007 and BS8485:2007: *"Code of practice for the characterisation and remediation from ground gas in affected developments"*.

CIRIA C665 aims to consolidate good practice in investigation, facilitate the collection of relevant data, instigate appropriate monitoring programmes, all in a risk based approach to gas contaminated land. As with BS8485, this document largely focuses on Methane and Carbon Dioxide. However, much of the text is also relevant to consideration of other contamination present in vapour phase.

BS8485, 2007 describes methods for the investigation and assessment of the ground gases methane and carbon dioxide provides recommendations for protection of new development on affected sites. This standard is not intended for the assessment of completed developments and considers only methane and carbon dioxide.

Both of these publications have been prepared to be generally consistent with CLR11, *Model Procedures for the management of land contamination,* (DEFRA and the Environment Agency, 2004a) and follow a step by step approach summarised below:-

1. Desk Study and Site Walkover
2. Development of a Preliminary Conceptual Model and Risk Assessment
3. Site Investigation (If deemed necessary from stage 2)
4. Risk Assessment and Site Characterisation
5. Recommendation and Mitigation

Where, the preliminary conceptual model has deemed further investigation necessary to characterise the ground gas regime, an appropriate site investigation and monitoring regime should be designed and undertaken. In-depth guidance to assist in the design of the investigation is provided within C665, which describes intrusive investigation techniques and provides guidance on selecting the number and location of monitoring wells based on the site specific conceptual model.

Waterman has generally followed the approach recommended in CRIRIA C665 with respect to characterising a site and determining the levels of gas protection methods required. This approach is generally consistent with the guidance provided in BS8485.

In accordance with C665, to assess the ground gas regime at a site, the ground gas monitoring data should be assessed by determining the Gas Screening Value (GSV) (l/hr) (BS8485 refers to the GSV as the Hazardous Gas Flow Rate). The GSV is calculated as follows:

GSV = (Measured Maximum CO_2 or CH_4 Gas Concentration (%) / 100) x Maximum Measured Gas Flow Rate from boreholes (l/hr)

Where the gas flow rate has been measured as less than the detection limit of the instrument used (ie <0.1 l/hr), C665 recommends that the detection limit for the Gas Analyser is used as the gas flow rate (ie 0.1l/hr).

The Gas Screening Value is used to classify the site, subject to the proposed end use of the site, falling into either Situation A or Situation B, as described below.

Situation A – For All Development Types except Low Rise Housing with a ventilated underfloor void (150mm)

For situation A, the Modified Wilson and Card classification system is used. This system attributes a Characteristic Situation (CS) value to the site/zone depending upon the calculated GSV. When attributing a CS, additional factors including the maximum recorded gas concentration and the maximum recorded gas flow rate should also be taken into account and may result in an increase in the CS value. Table I.2 below, outlines the CS values associated GSV's and additional factors which must be taken into account.

Modified Wilson and Card Classification

Characteristic Situation (CIRIA 149)	Risk Classification	Gas screening value (CH_4 CO_2) l/hr	Additional Factors	Typical source of generation
1	**Very low risk**	**<0.07**	Typically methane ≤1% and / or carbon dioxide ≤5%. Otherwise consider increase to CS 2.	Natural soils with low organic content 'Typical' made ground
2	**Low risk**	**<0.7**	Borehole air flow rate not to exceed 70 l/hr. Otherwise consider increase to CS 3.	Natural soil, high peat/organic content. 'Typical' made ground
3	**Moderate risk**	**<3.5**		Old landfill, inert waste, mineworking flooded
4	**Moderate to high risk**	**<15**	Quantitative risk assessment required to evaluate scope of protective measures.	Mineworking – susceptible to flooding, completed landfill (WMP 26B criteria)
5	**High risk**	**<70**		Mineworking unflooded inactive with shallow workings near surface
6	**Very High risk**	**>70**		Recent landfill site

Notes:

1) Gas screening value: litres of gas / hour is calculated by multiplying the gas concentration (%) by the measured borehole flow rate (l/hr)
2) Source of gas and generation potential/performance must be identified.
3) If there is no detectable flow use the limit of detection of the instrument.

Once the characteristic situation has been determined, the requirements and scope of gas protection measures can be determined based on Table I.3 below (based on guidance provided within C665):

Modified Wilson and Card Protection Measures

CS*		Residential building (not those subject to NHBC Classification Method		Office/commercial/industrial development	
	Risk Classification	No. of levels of protection	Typical scope of protective measures	No. of levels of protection	Typical scope of protective measures
1	**Very low risk**	**None**	No special precautions	None	

CS*		Residential building (not those subject to NHBC Classification Method		Office/commercial/industrial development	
	Risk Classification	No. of levels of protection	Typical scope of protective measures	No. of levels of protection	Typical scope of protective measures
2	**Low risk**	**2**	a) Reinforced concrete cast in situ floor slab (suspended, non-suspended or raft) with at least 1200g DPM[2,7] and underfloor venting. b) Beam and block or pre-cast concrete and 2000g DPM[7]/ reinforced gas membrane and underfloor venting. All joints and penetrations sealed	1 to 2	a) Reinforced concrete cast in situ floor slab (Suspended, non-suspended or raft) with at least 1200g DPM[2,7]. b) Beam and block or pre-cast concrete slab and minimum 2000g DPM / reinforced gas membrane. c) Possibly underfloor venting or pressurisation in combination with a) and b) depending on use. All joints and penetrations sealed
3	**Moderate risk**	**2**	All types of floor slab as above. All joints and penetrations sealed. Proprietary gas resistant membrane and passively ventilated or positively pressurised underfloor sub-space.	1 to 2	All types of floor slab as above. All joints and penetrations sealed. Minimum 2000g/reinforced gas proof membrane and passively ventilated underfloor sub-space or positively pressured underfloor sub-space.
4	**Moderate to high risk**	**3**	All types of floor slab as above. All joins and penetrations sealed. Proprietary gas resistant membrane and passively ventilated underfloor sub-space or positively pressurised underfloor sub-space, oversite capping or binding and in ground venting layer.	2 to 3	All types of floor slab as above. All joins and penetrations sealed. Proprietary gas resistant membrane and passively ventilated or positively pressurised underfloor sub-space.
5	**High risk**	**4**	Reinforced concrete cast in situ floor slab (suspended, non-suspended or raft). All joints and penetrations sealed. Proprietary gas resistant membrane and ventilated or positively pressurised underfloor sub-space, oversite capping and in ground venting layer and in ground venting wells or barriers	3 to 4	Reinforced concrete cast in situ floor slab (suspended, non-suspended or raft). All joins and penetrations sealed. Proprietary gas resistant membrane and passively ventilated or positively pressurised underfloor sub-space with monitoring facility. In ground venting wells or barriers.

CS*		Residential building (not those subject to NHBC Classification Method		Office/commercial/industrial development	
	Risk Classification	No. of levels of protection	Typical scope of protective measures	No. of levels of protection	Typical scope of protective measures
6	**Very high risk**	**5**	Not suitable unless gas regime is reduced first and quantitative risk assessment carried out to assess design of protection measures in conjunction with foundation design.	4 to 5	Reinforced concrete cast in-situ floor slab (suspended, non-suspended or raft). All joints and penetration sealed. Proprietary gas resistant membrane and actively ventilated or positively pressurised underfloor sub-space with monitoring facility, with monitoring. In ground venting wells and reduction of gas regime.

Notes:

1) Typical scope of protective measures may be rationalised for specific developments on the basis of quantitative risk assessments.
2) Note, the type of protection is given for illustrative purposes only. Information on the detailing and construction of passive protection measures is given in BR414 [Ref: 16]. Individual site specific designs should provide the same number of separate protective methods for any given characteristic situation.
3) In all cases there should be minimum penetration of ground slabs by services and minimum number of confined spaces such as cupboards above the ground slab. Any confined spaces should be ventilated.
4) Foundation design must minimise differential settlement particularly between structural elements and ground baring slabs.
5) Floor slabs should provide an acceptable formation on which to lay the gas membrane. If a block beam floor is used it should be well detailed so it has no voids in it that membranes have to span and all holes for service penetrations should be filled. The minimum density of the blocks should be 600kg/m^3 and the top surface should have a 4:1 sand cement grout brushed into all joints before placing any membranes (this is also good practice to stabilise the floor and should be carried out regardless of the need for gas membranes).
6) The gas resistant membrane can also act as the damp proof membrane.
7) DPM = Damp Proof Membrane

Situation B – For Low Rise Housing with a ventilated underfloor void (min 150mm)

Situation B should be used for low-rise residential housing with gardens and sub-floor void. Where a sub-space void is not proposed, the development should be assessed using the situation A classification system above.

For situation B, the National House Building Council's (NHBC) Traffic Light classification system is used. This system attributes a colour to a site/zone depending upon the calculated GSV. As with the Wilson and Card system, in addition to the GSV, additional factors including the maximum recorded gas concentration and the maximum recorded gas flow rate must be taken into account when determining the Traffic Light classification. Table I.4, outlines the Traffic Light classification system, based on the calculated GSV's and additional factors which must be taken into account.

NHBC traffic light system for 150mm void

Traffic Light	Methane	Carbon Dioxide

	Typical Maximum Concentration (% v/v)	Gas Screening Value (GSV) l/hr	Typical Maximum Concentration (% v/v)	Gas Screening Value (GSV) l/hr
Green				
	1	0.16	5	0.78
Amber 1				
	5	0.63	10	1.56
Amber 2				
	20	1.56	30	3.13
Red				

Notes:

- The worst gas regime identified at the site, either methane or carbon dioxide, recorded from monitoring in the worst temporal conditions, will be the decider as to what Traffic Light and GSV is allocated.
- Generic GSVs are based on guidance contained within latest revision of Department of the Environment and the Welsh Office (2004 edition) “The Building Regulations: Approved Document C” [Ref:17] and used a sub-floor void of 150mm thickness.
- This assessment is based on a small room e.g. downstairs toilet with dimensions of 1.5 x 2.5m, with a soil pipe passing into the sub-floor void.
- The GSV, in litres per hour, is as defined as the bore hole flow rate multiplied by the concentration of the particular gas being considered.
- The typical maximum concentrations can be exceeded in certain circumstances should the conceptual site model indicate it is safe to do so. This is where professional judgement will be required based on a thorough understanding of the gas regime identified at the site where monitoring in the worst case temporal conditions has occurred.
- The GSV threshold should not generally be exceeded without completion of a detailed gas risk assessment taking into account site specific conditions.

Once the Traffic Light classification has been determined, the requirements and scope of gas protection / mitigation measures can also be determined based on Table I.5 below (based on guidance provided within CIRIA C665):

Gas Protection Measures for Low-Rise Housing Development Based Upon Allocation NHBC Traffic Light (Boyle and Witherington, 2006)

Traffic Light Classification	Protection Measures Required
Green	Negligible gas regime identified and gas protection measures are not considered necessary.
Amber 1.	Low to intermediate gas regime identified, which requires low-level gas protection measures, comprising a membrane and ventilated sub-floor void to create a permeability contrast to limit the ingress into buildings. Gas

	protection measures should be as prescribed in BRE Report 414 (Johnson 2001). Ventilation of sub-floor void should facilitate a minimum of one complete volume change per 24 hours.
Amber 2.	Intermediate to high gas regime identified, which requires high level gas protection measures, comprising a membrane and ventilated sub-floor void to create a permeability contrast to prevent the ingress of gas into buildings. Gas protection measures should be as prescribed in BRE Report 414. Membranes should always be fitted by a specialist contractor. As with Amber 1, ventilation of the sub-floor void should facilitate a minimum of one complete volume change per 24 hours. Certification that these passive protection measures have been installed correctly should be provided.
Red	High gas regime identified. It is considered that standard residential housing would not normally be acceptable without a further Gas Risk Assessment and / or possible remedial mitigation measures to reduce and / or remove the source of gas.

Volatile Organic Compounds

The Building Regulations 2000 Approved Document C (2004 Edition) also refers to volatile organic carbons (VOCs). These are primarily assessed by examination of the VOC content of site soils. Further guidance on VOCs is provided in *“The VOCs Handbook; Investigating, assessing and managing risks from inhalation of VOCs at land affected by contamination”*, CIRIA Report C682, 2009.

For former landfill sites the risk from a wider range of trace gases are considered on a site specific basis when appropriate.

UK and Ireland Office Locations