Report

Brightwater
TREATMENT SYSTEM

Appendix 5A
Pressuremeter Testing

December 2005

King County
Department of Natural Resources and Parks
Wastewater Treatment Division

Summary of the Preliminary Pressuremeter Testing for the King County Brightwater Tunnel Project

submitted to

Camp Dresser & McKee Inc.

11811 N.E. 1st Street, Suite 201
Bellevue, WA 98005

September 2003
C-268

HUGHES INSITU ENGINEERING INC.
Suite 804, 938 Howe Street, Vancouver B.C. Canada V6Z-1N9
Phone (604) 331-4451 Fax (604) 331-4452

CONTENTS

TABLES

FIGURES

PHOTOGRAPHS

APPENDIX

Basic pressuremeter data
Plots of pressure/expansion for modulus determination, and pressure/log expansion for shear strength and limit stress determination

1.0 INTRODUCTION

This report outlines the results of a pressuremeter study, conducted from May 11—August 18, 2003, at selected locations along the Brightwater Tunnel alignment. Drilling of the hole for the pressuremeter, and deployment of the pressuremeter was conducted by Cascade Drilling, Inc., Seattle, WA, Gregory Drilling, Inc. Seattle, WA. and Crux Subsurface, Inc., Spokane, WA. The field work was conducted by Hughes Insitu Engineering Ltd., Vancouver, B.C. under supervision from Mr. David Yonemitsu for Camp Dresser & Mckee Inc (CDM) Bellevue, WA.

2.0 PRESSUREMETER

The pressuremeter used for this study is a monocell pressuremeter. At the center of the pressuremeter are three electronic displacement sensors, spaced 120 degrees apart. Over these sensors is the flexible membrane, clamped at each end, which is pressurized to deform the adjacent material. A protective sheet of stainless steel strips covers the membrane. The pressuremeter was expanded by regulating the flow of from a gas bottle of compressed nitrogen. The electronic signals from displacement sensors and the pressure sensor are transmitted by cable to the surface. During the test, the average expansion against pressure curve is displayed on a computer screen.

The essential details of the instrument are shown in Fig. 1.

3.0 OBJECT OF THIS PRELIMINARY STUDY

Although many successful pressuremeter tests have been conducted in the Seattle area most of that testing has been within the upper 150 ft. The testing for the Brightwater tunnel was much deeper, up to 400 ft in depth. To operate at these depths special drills had to be employed which were capable of drilling to those depths through the dense Seattle area glacial materials. The initial object of the program was to determine whether successful testing could be conducted with this equipment and what modification were required to complete this study. The results of this initial study of six tests was summarized in Report C-268 presented in July 2003. With suitable modifications to the system the program successfully completed 46 tests, to a maximum depth of 421 feet.

4.0 DEPLOYMENT OF THE PRESSUREMETER

There are two aspects for successful pressuremeter tests.

1. A pilot hole approximately 5 ft long has to be drilled, of a diameter close to that of the pressuremeter (3 in.).
2. The pressuremeter must be lowered into this pilot hole and withdrawn after the test, without getting wedged inside the casing or damaged.

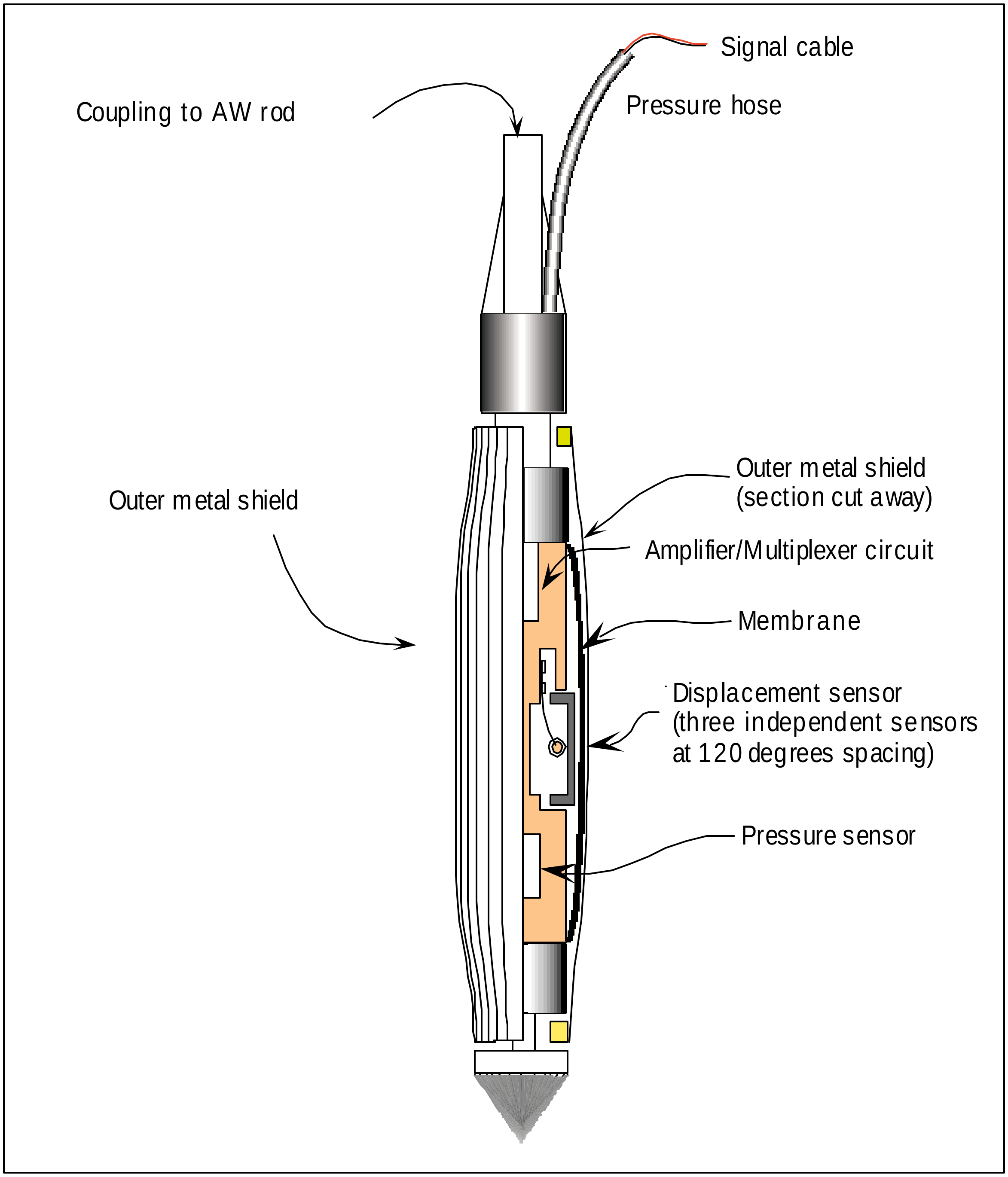


Figure 1. Schematic drawing of pressuremeter

4.1 Formation of the pilot hole

In normal deposits of sands silts or clays cutting a pilot hole is usually not a problem. A hole can readily be cut to the correct diameter with an N-size core barrel or tricone bit. In this study, a $2^{15}/16$ inch tricone bit was used to form the hole for all of the tests. After the initial testing the same $2^{15}/16$ inch bit on a stabilizer rod was used on all subsequent pilot holes. It was deployed in the conventional manner on separate drill rods separate from the wireline system. In general, this cut a satisfactory hole in all but two cases. In these zones, the holes in the granular material were washed oversize. The test depths and comments are presented in Table I.

5.0 TEST PROCEDURE

After the pressuremeter was placed at the bottom of the hole the pressuremeter was expanded by regulator the flow of compressed nitrogen from a gas cylinder. The aim of the test as illustrated in Figs. 2A and 2B was:

1. Establish the general shape of the loading curve from which the "limit" pressure PL could be determined.
2. To determine the creep strain which would occur as the pressure is held constant for four minutes prior to unloading. The relative amount of the creep strain can be used to give a qualitative indication of the cohesive nature of the material.
3. To determine the average slope of the unload reload curves (G_{ur}). To determine the shape of the final unloading curve.

If the creep strains are significant, they can be used to establish the equilibrium pressure on unloading which balances the *in-situ* pressure in the ground. This is done is a stepwise manner. On the final unloading stage the pressure is held constant at a pressure estimated to be below the *in-situ* pressure. The strains are then monitored with time. Then after a few minutes the pressure is raised, and the strains again monitored with time. If the movements are outwards then the pressure is above the *in-situ* lateral stress. The process can be repeated in small steps until the equilibrium pressure is established.

6.0 ANALYSIS OF THE PRESSUREMETER DATA

There are three methods of considering the pressuremeter data. In this report they are referred to as the "Empirical", "Direct", and "Model" methods.

The "Empirical" method, developed in France and used almost exclusively on Ménard pressuremeter tests, determined two parameters from the test – the limit pressure P_L and the Ménard Modulus E_M. The design parameters such as strength and stiffness are empirically related to these parameters. There is no attempt to develop fundamental material properties.

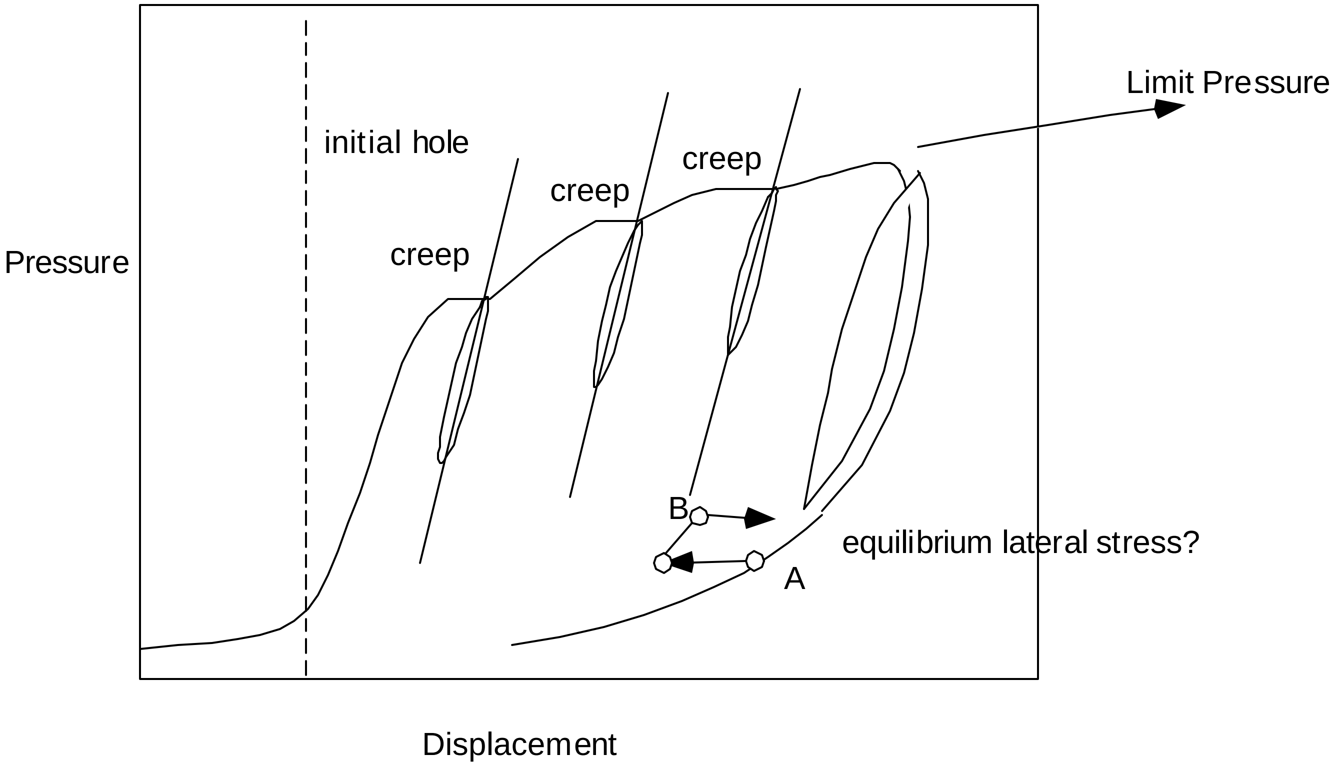


Figure 2a. Ideal pressuremeter curve

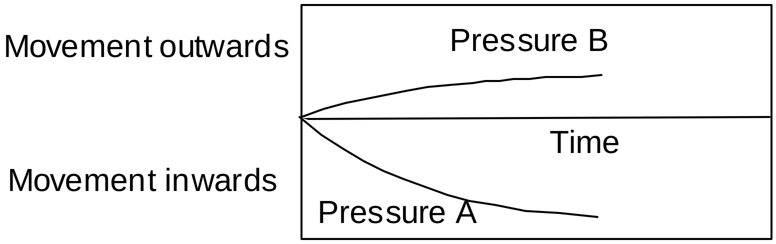


Figure 2b. Creep movement during final unloading from points A and B

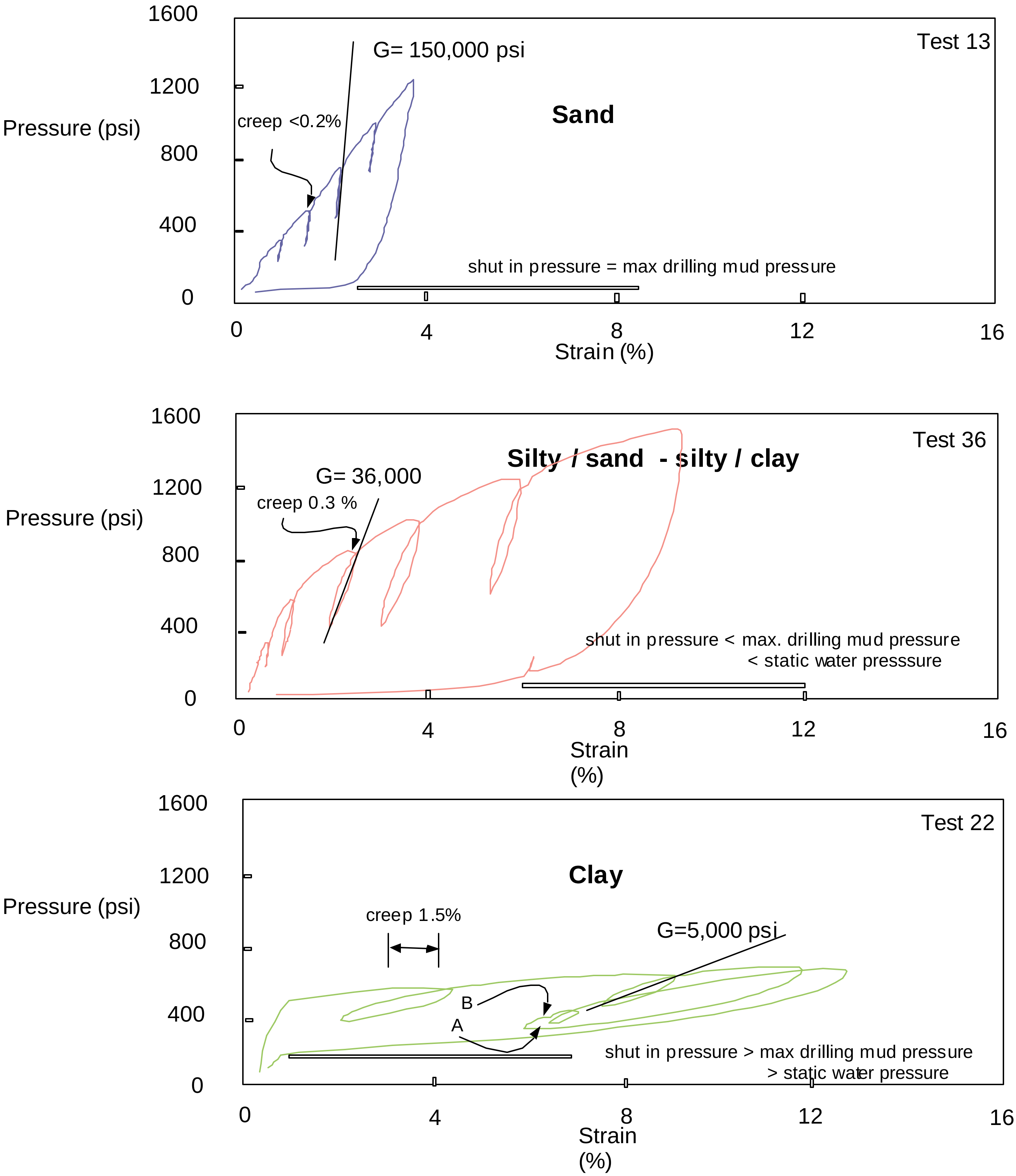
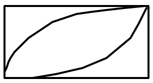


Figure 3 Typical pressuremeter curves



In the “Direct” method of analysis the pressuremeter data is assumed to follow a particular mathematical form depending on the material type. The field data is then manipulated to determine the strength parameters. The common method is to re-plot the data in either a log or semi-log form, and from the slope determine the fundamental material properties.

In the “Model” method, the fundamental material parameters required for the particular soil model are estimated. For clays, the simplest model requires an estimate of the undrained strength, the *in-situ* stress and the linear secant shear modulus. For purely frictional materials, a friction angle, lateral stress and modulus are the minimum required parameters. These parameters are then used to predict the ideal pressuremeter curve. This ideal curve can then be compared with the field data. Adjustments can be made to the parameters until a suitable match is obtained. Using interactive computer graphics this process can be accomplished quickly. Hence, if a match can be obtained, the ***set*** of parameters used in predicting this ideal curve will represent the behaviour of the clay: the values of the shear stress with the appropriate lateral stress and modulus are the end result. In general, the models selected are those for which there is a closed-form solution which allows for the rapid generation of an ideal pressuremeter curve.

In this data report, both the Direct and the Model approaches have been used to develop an indication of the likely material behavior in terms of the fundamental material parameters. The limit pressures – the basic data for the empirical method – are tabulated in Table II.

7.0 GENERAL OBSERVATIONS OF THE TESTS

The tests can be divided into three groups as a function of compressibility. Typical representative tests are presented in Fig. 3.
The sand type test exhibits the highest unload-reload modulus having a shear modulus of 150,000 psi. The creep strains before unloading are very small—typically less than 0.2 %. On final unloading, the unload curve is essentially straight until the pressure reduces to the water pressure in the drill hole. As the pressure is reduced below this pressure the membrane collapses back on the pressuremeter.

The intermediate material—less pervious silty sands or silty clay material—exhibits a larger creep component prior to unloading. The unload-reload modulus is much less steep, having a modulus of 36,000 psi. The unloading curve is distinctly curved as the material fails inwards on the pressuremeter. The shut-in pressure is usually less than the static water pressure. This is a result of the low permeability restricting the flow of water through the silty clay to provide force to close the membrane.

The least permeable material—the clay—exhibits a large creep movement over 1.5% strain. The modulus determined from the slope of the unload-reload loop has the lower value of these materials of 5,000 psi. Further, there is significant hysteresis in the unload-reload loops. The shut-in pressure is much higher than the maximum drilling mud pressure or the static water pressure. The possible explanation for this is a high *in-situ* lateral stress, forcing the closure of the membrane. A further indication of the possible presence of a high lateral stress is given by the creep tests on the first large unloading. At point A, the pressure was held constant at 320 psi.

During that stage the membrane moved inwards. The pressure was then raised to B (400 psi) at which stage the membrane moved outwards. This would suggest that the total balance pressure is possibly in the range of 300 psi. This is approximately twice the existing vertical stress.

7.1 Shear strength

7.11 Direct Method — Constant volume shear strength

The test is analyzed by assuming that the material behaves according to a particular soil model. The model commonly chosen – the Gibson model – (Mair and Wood 1987) assumes that the material fails at a constant shear strength. Hence, creep or consolidation strains are assumed to be insignificant. The constant shear strength can then be determined by the slope of a plot of the pressure against the log of the strain.

An example of this log /normal plot for Test 3 is given in Fig. 4 (the log/normal plots for all of the tests are presented in the appendix). In this example, the slope of the log/normal curve is well defined, from which the slope can be determined with reasonable certainty.

The pressure at which the pressuremeter has doubled in volume is known as the limit pressure. This pressure is determined by projecting the estimated linear pressure/log strain line until the strain has reached 41%, at which point the pressuremeter has doubled in volume. In Test 3, the calculated limit pressure is 1100 psi and the calculated shear strength is 130 psi. The limit pressure for all of the tests is presented in Table II.

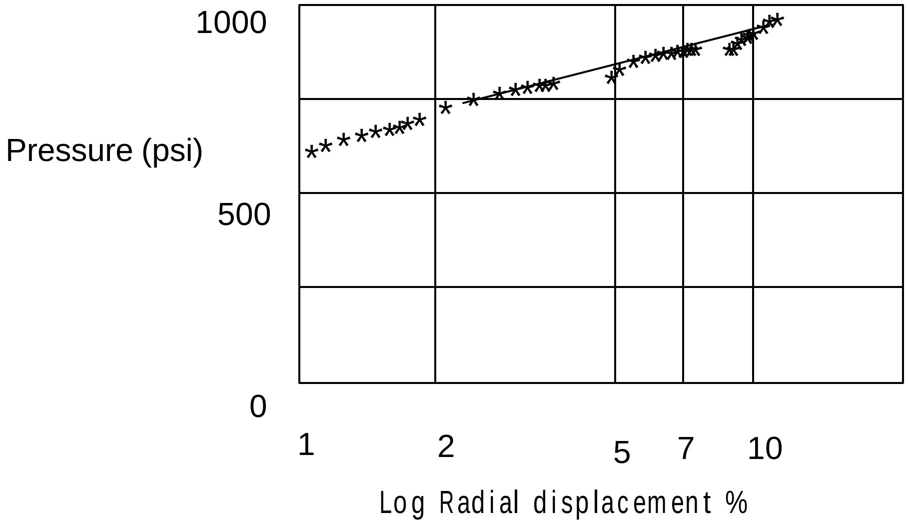


Figure 4. Pressure/log strain for Test 3

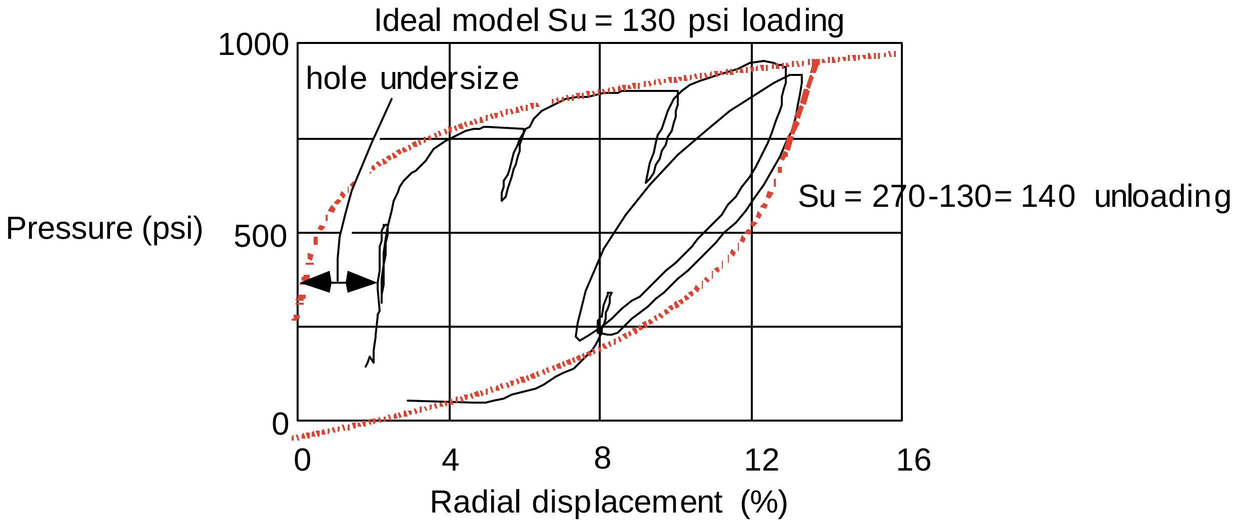


Figure 5. Cohesive model analysis of loading and unloading stages of Test 3

8.0 MODEL METHOD OF ANALYSIS

8.12 Model Methods

8.121 Cohesive Model

In Fig. 5 is an ideal pressuremeter curve for Test 3 that provides a reasonable fit to the field data, assuming that the soil behaves as a cohesive material with no friction. The cohesive strength is 130 psi, similar to that determined by the direct method. Further, as the ideal model curve follows the data reasonably well, the material is probably behaving in a cohesive manner. The results of this analysis on the other tests are given in the Appendix and summarized in Table II.

8.122 Frictional Model

In Fig. 6 is an ideal pressuremeter curve for Test 6 that provides a reasonable fit to the field data assuming that the soil behaves as a frictional material with no cohesion. Hence, the material is probably behaving as a frictional material. The low friction angle of 33 degrees suggests that there is a considerable amount of silt within the matrix of the sand. The results of this analysis on the other tests are given in the Appendix and summarized in Table II.

9.0 RELAXATION OF THE SHAFT WALL

An indication of the likely relaxation of the soil adjacent to the shaft wall can be obtained by calculating the ideal response of the soil as the pressure is reduced on the wall adjacent to the wall assuming the soil has the properties as determined from the pressuremeter test. The material at Test 3 would likely behave in a manner as indicted by Fig. 7. As the pressure is reduced from the lateral stress at point A the soil moves inwards to point B. The maximum movement for a 100-inch shaft is likely to be in the range of 0.7 inches.

10.0 REFERENCES

Mair, R.J., and Wood, D.M. 1987. Pressuremeter testing: methods and interpretation. CIRIA Ground Engineering Report. Butterworths, London.

ASTM D4719. 1994. Standard test method for pressuremeter testing in soils.

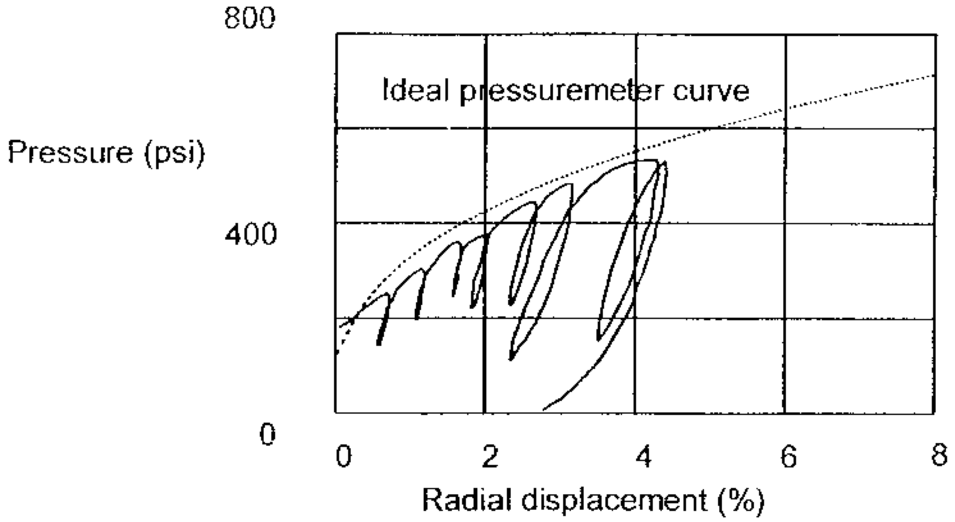


Figure 6. Ideal frictional model for Test 6

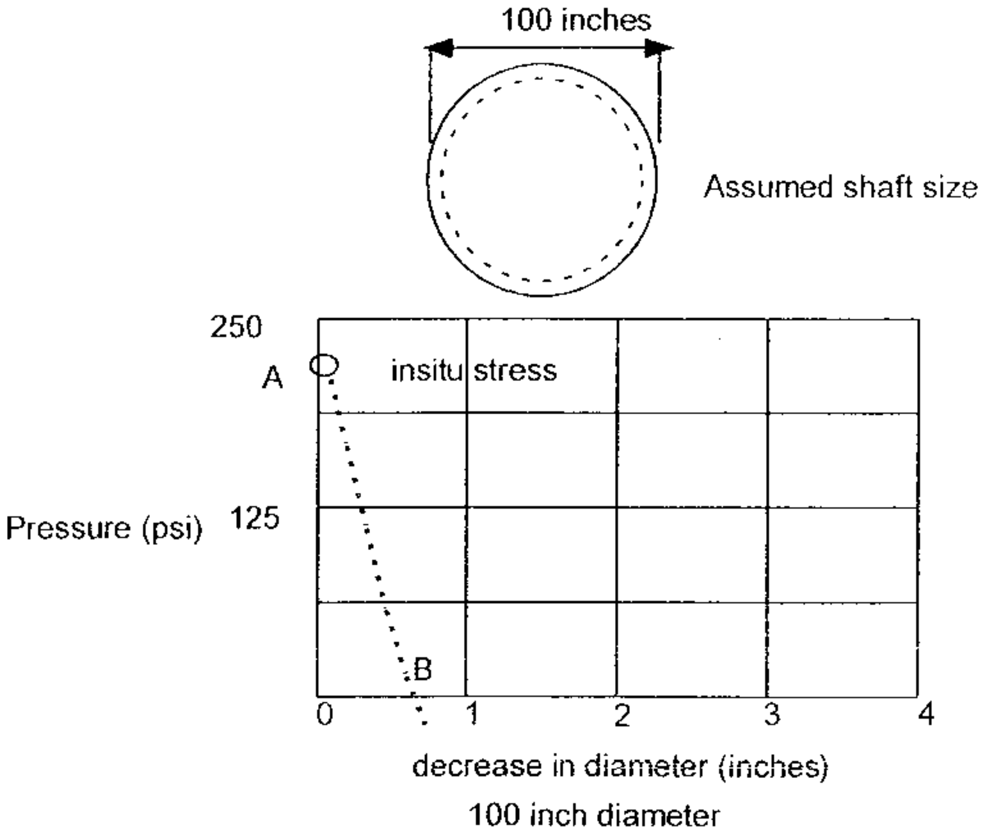


Figure 7. Convergence of the shaft wall during stress unloading

Table I. Test depth and material type

Test	Hole	Depth (ft)	Material	Geologic series	Comments
BW1	E-339	186.1	clay	Qpfnl	hole oversize
BW2	E-210	207	clay	Qpogm	hole undersize
BW3	E-339	266.2	clay	Qpfnl	hole undersize
BW4	E-339	264.7	clay	Qpfnl	hole undersize*
BW5	E-207	306	sand	Qpfnl	hole washed out
BW6	E-207	304.5	sand	Qpfnl	hole oversize
BW7	E-223	143	sand	Qpogf	
BW8	E-314	170	silt	Qpogl	hole collapsed
BW9	E-223	180	sand	Qpogf	
BW10	E-223	178.5	sand	Qpogf	
BW11	E-223	290	clay	Qpogl	
BW12	E-223	288.5	clay	Qpogl	
Bw13	E-211	180	sand	Qpogt	
BW14	E-211	178	sand	Qpogt	
BW15	E-211	231	clay	Qpogl	
BW16	E-211	229.5	clay	Qpogl	
BW17	E-211	280	clay	Qpogl	hole washed out
BW18	E-310	210	clay	Qpogl	membrane failed
BW21	E-334	174	clay	Qpogl	
BW22	E-334	173.5	clay	Qpogl	
BW23	E-313	205	gravel	Qpogf	

Table I. Test depth and material type

Test	Hole	Depth (ft)	Material	Geologic series	Comments
BW24	E-406	345	clay	Qpfnl	
BW25	E-406	343.5	clay	Qpfnl	hole too large
BW26	E-406	415	silt	Qpfnl	
BW27	E-406	413	silt	Qpfnl	
BW28	E-214	286	clay	Qpogl	
BW29	E-214	284	clay	Qpogl	
BW30	E-214	320	clay	Qpogl	
BW31	E-214	318.5	clay	Qpogl	
BW32	E-412	175	silt	Qpogl	
BW33	E-412	173.5	silt	Qpogl	hole too large
BW34	E-412	172.5	silt	Qpogl	
BW35	E-412	255	silt	Qpogl	
BW36	E-412	253.5	silt	Qpogl	
BW37	E-403	242	sand	Qpfnf	
BW38	E-403	239.5	sand	Qpfnf	
BW39	E-414	198	silt	Qpogt	
BW40	E-414	196.5	silt	Qpogt	
BW41	E-408	421	sand	Qpfnl	
BW42	E-408	419.5	sand	Qpfnl	
BW43	E-416	344	silt	Qpogl	
BW44	E-416	342.5	silt	Qpogl	
BW45	E-416	389	clay	Qpogl	
BW46	E-416	388	clay	Qpogl	hole too large

Note: As there was no core at the pressuremeter location, the material type has been estimated from the core taken above and below the test interval.

Table II. Basic material properties from pressuremeter tests

Test	Hole	Depth (ft)	Limit pressure (psi)	Pressure at 10% strain	Unload-reload modulus (psi)	Initial modulus (psi)	Static water head at test level (ft)	Static pressure (psi)	Shut-in water pressure (psi)	Max. drill mud pressure	Creep (%)	Material	Test quality
BW1	E-339	186.1	>500		10,000	2,500	59.6	25	70	80	0.5	clay	1
BW2	E-210	207	900	760	11,000	>3,000	152	65	70	90	-	clay	4
BW3	E-339	266.2	1,100	850	15,000	6,500	167.29	71	40	115	1	clay	4
BW4	E-339	264.7	1,100	850	11,000	>1,000	165.79	71	30	114	1.5	clay	4
BW5	E-207	306			10,000	2,200	139	60	120	132	-	sand	1
BW6	E-207	304.5	1,100	(850)	33,000	5,400	137.5	59	120	131	<0.2	sand	3
BW7	E-223	143	1,200	(700)	40,000	14,000	53	23	40	62	<0.2	sand	3
BW9	E-223	180	1,700	1,200	35,000	6,000	90	39	30	80	<0.2	sand	5
BW10	E-223	178.5	1,400	900	20,000	6,000	88.5	38	30	77	<0.2	sand	5
BW11	E-223	290	800	550	7,500	3,000	105.26	45	140	125	0.4	clay	4
BW12	E-223	288.5	1,200	(800)	12,000	4,700	103.76	44	80	124	0.4	clay	3
Bw13	E-211	180	3,300	>2,000	150,000	17,000	110	47	70	78	<0.1	sand	4
BW14	E-211	178	3,300	>2,000	200,000	15,000	108	46	70	77	<0.1	sand	4
BW15	E-211	231	1,600	1,000	17,000	>5,000	161	70	120	100	0.6	clay	5
BW16	E-211	229.5	1,500	1,000	18,000	7,000	159.5	68	120	99	0.6	clay	5

Table II. Basic material properties from pressuremeter tests(continued)

Test	Hole	Depth (ft)	Limit pressure (psi)	Pressure at 10% strain	Unload-reload modulus (psi)	Initial modulus (psi)	Static water head at test level (ft)	Static pressure (psi)	Shut-in water pressure (psi)	Max. drill mud pressure	Creep (%)	Material	Test quality
BW18	E-310	210	2,000	1,100	35,000	14,000	123	53		91	0.8	clay	3
BW21	E-334	174	1,000	850	5,500	>2,300	167.51	72	300	75	1.0	clay	4
BW22	E-334	173.5	800	700	5,000	>2,000	167.01	71	200	74	1.0	clay	4
BW23	E-313	205	1,100	950	27,000	>4,000	22	9.5	20	89	0.4	silt ?	4
BW24	E-406	345	1,100	900	22,000	4,200	94	50	140	150	0.4	clay	5
BW26	E-406	415	2,500	(>2,000)	50,000	33,000	164	71	50	180	<0.1	sand	4
BW27	E-406	413	3,100	(>1,500)	41,000	13,000	162	70	30	180	<0.1	sand	4
BW28	E-214	286	1,900	(1,000)	29,000	12,000	181	78	140	124	0.4	clay	4
BW29	E-214	284	1,900	(1,200)	33,000	15,000	179	77	140	123	0.5	clay	4
BW30	E-214	320	1,600	(1,200)	35,000	6,400	215	93	160	138	0.5	clay	4
BW31	E-214	318.5	1,300	900	21,000	>4,000	213.5	92	80	137	1.5	clay	4
BW32	E-412	175	1,700	(1,200)	36,000	5,000	101	44	30	76	1.0	silt	4
BW34	E-412	172.5	1,600	(900)	40,000	6,000	98.5	42	30	74	0.8	silt	5
BW35	E-412	255	1,600	(1,500)	45,000	2,500	181	78	0	110	<0.2	sand	5
BW36	E-412	253.5	2,400	1,500	36,000	24,000	179.5	77	30	109	<0.2	sand	5

Table II. Basic material properties from pressuremeter tests (continued)

Test	Hole	Depth (ft)	Limit pressure (psi)	Pressure at 10% strain	Unload-reload modulus (psi)	Initial modulus (psi)	Static water head at test level (ft)	Static pressure (psi)	Shut-in water pressure (psi)	Max. drill mud pressure	Creep (%)	Material	Test quality
BW37	E-403	242	2,000	1,300	28,000	15,000	76	33	0	105	0.2	sand	5
BW38	E-403	239.5	1,700	1,200	33,000	14,000	73.5	32	0	104	0.3	sand	5
BW39	E-414	198	2,500	(>1,500)	53,000	16,000	98	42	80	86	0.5	silt	5
BW40	E-414	196.5	2,100	(>1,500)	60,000	21,000	96.5	42	0	85	0.4	silt	4
BW41	E-408	421	2,100	1,200	44,000	17,000	135	58	100	183	0.3	silt	5
BW42	E-408	419.5	2,000	1,400	40,000	11,000	133.5	57	30	182	0.3	silt	5
BW43	E-416	344	1,800	1,200	33,000	6,000	156	68	180	149	0.5	clay	5
BW44	E-416	342.5	1,800	1,200	44,000	10,000	157	68	110	148	0.2	silt	4
BW45	E-416	389	1,500	(1,200)	28,000	6,000	178	77	210	168	0.6	clay	4
BW46	E-416	388	1,700	(>1,000)	43,000	9,000	177	76	210	167	0.8	clay	2

Note:

1. The final column is a qualitative estimate of the quality of the test based on a scale of 0 to 5 with 5 being the best
2. The creep amount it the approximate amount of creep after a four minute pressure hold prior to the first unloading loop.
3. The material type as identified from the test data. In some instances this is different from that indicated by the core runs above and below the pressuremeter test level shown in Table I.
4. The estimation of the limit pressure requires the complete shape of the pressure expansion curve. In many instances on of the strain sensor reached a limit before the shape of the curve could be established. Projecting this limited section of the pressuremeter curve to the stage where the expansion has doubled can overestimate the limit pressure. A more consistent approach is to use the pressure at 10% circumferential strain to give an indication of the relative strength of the materials. Where the strain reached in the test has not reached 10% an estimate of the pressuremeter has been made and placed in brackets.

APPENDIX

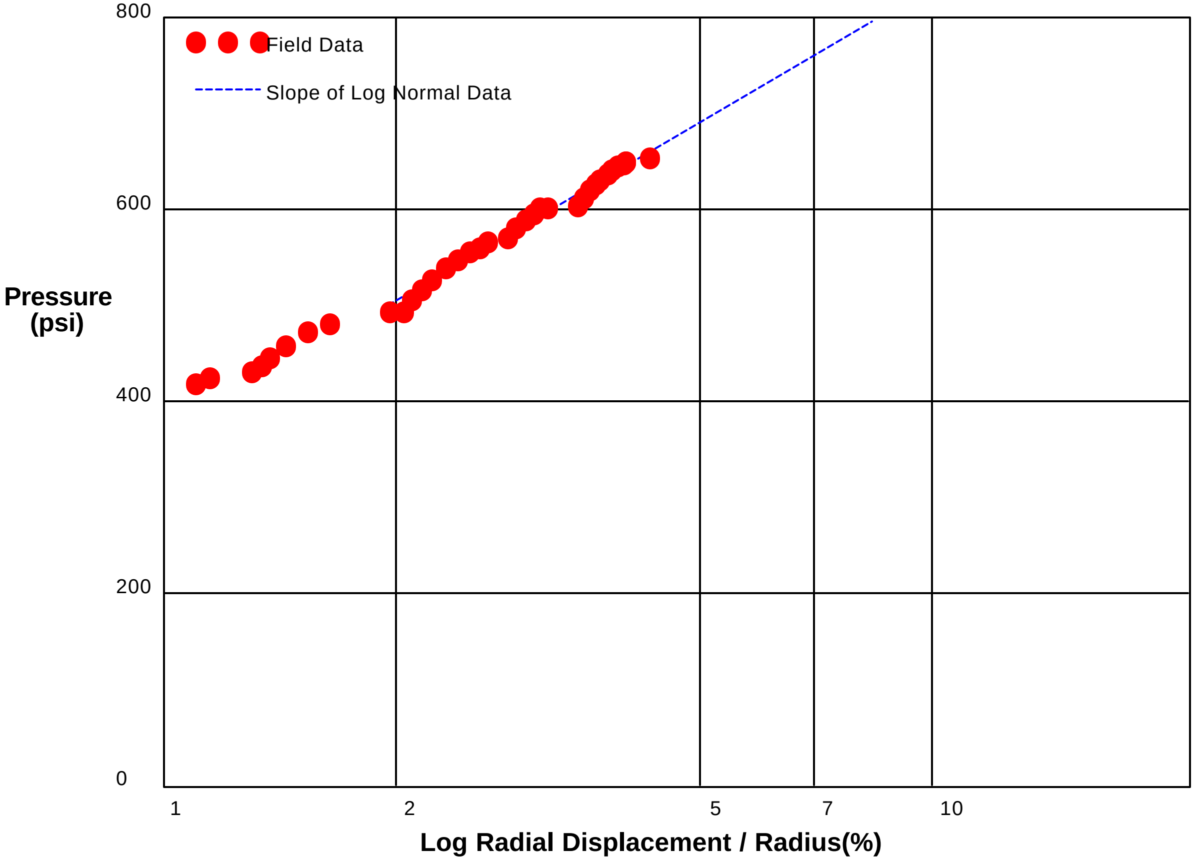
Basic pressuremeter data

Plots of pressure/expansion for modulus determination, and pressure/log expansion for shear strength and limit stress determination

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **May 21, 2003**

Hole No E-707 **Depth 304.5 ft** C:\DATA\C-268\BW6COM.P



Shear Strength	**203.8 psi**
Limit Pressure	**1120 psi**

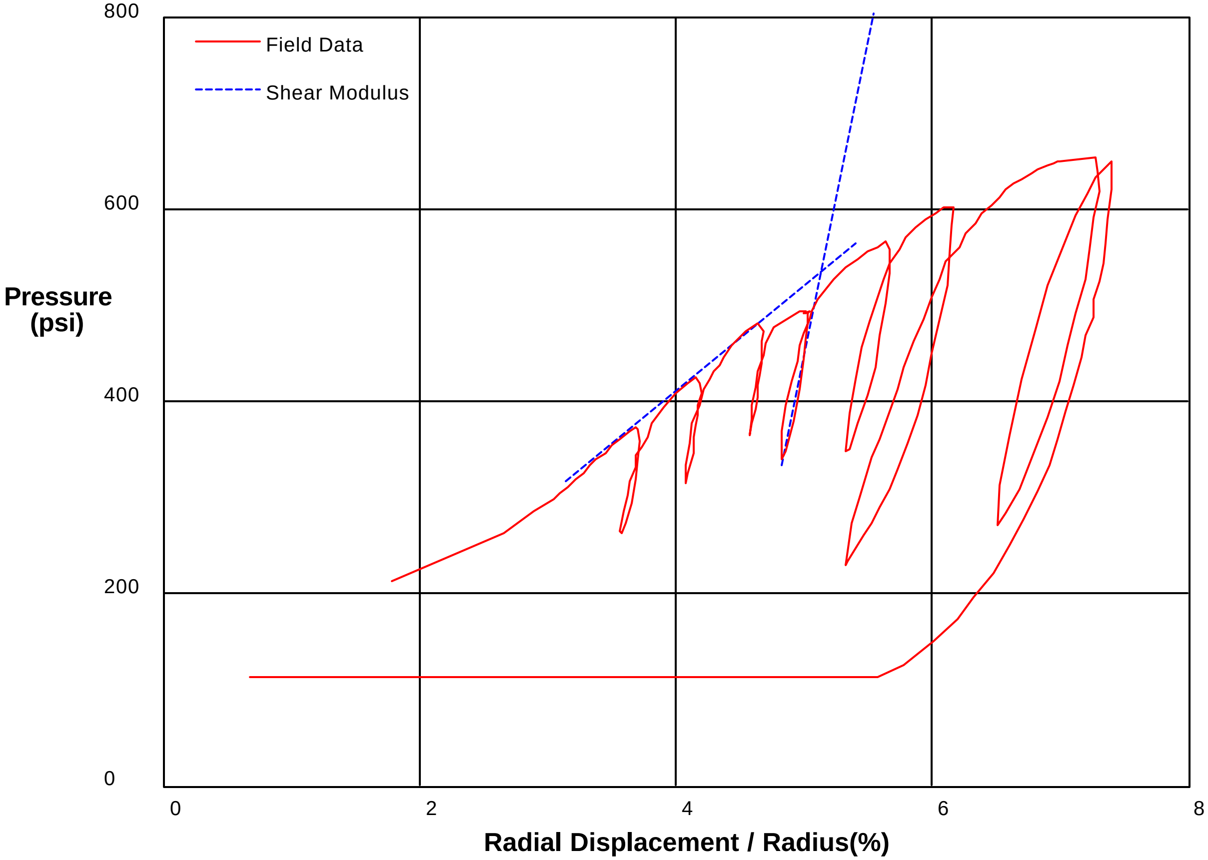
shift 7

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **May 21, 2003**

Hole No. E-207 **Depth 304.5 ft** **File C:\DATA\C-268\BW6COM.P**



Shear Modulus 5499 psi

Shear Modulus 32753 psi

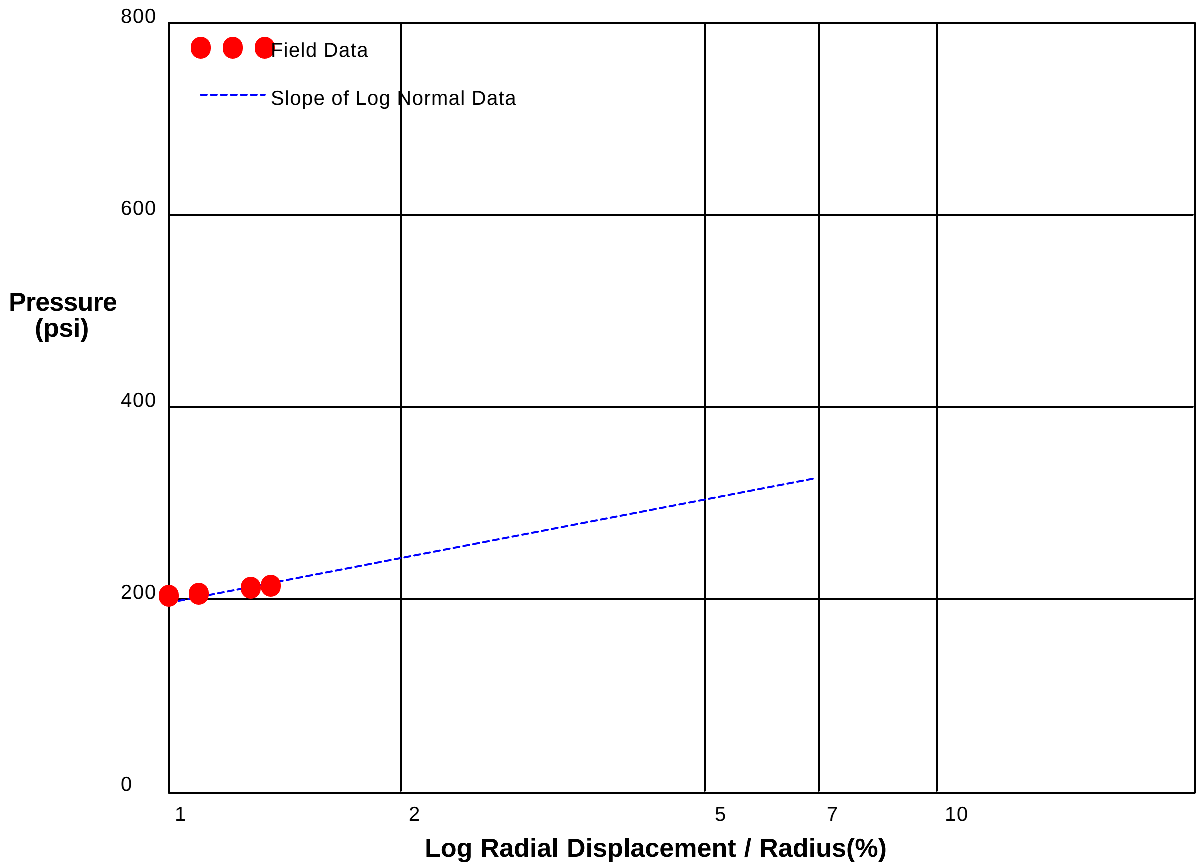
shift 4

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **May 21, 2003**

Hole No E-207 **Depth 306 ft** C:\DATA\C-268\BW5.P



Shear Strength	**66.8 psi**
Limit Pressure	**445 psi**

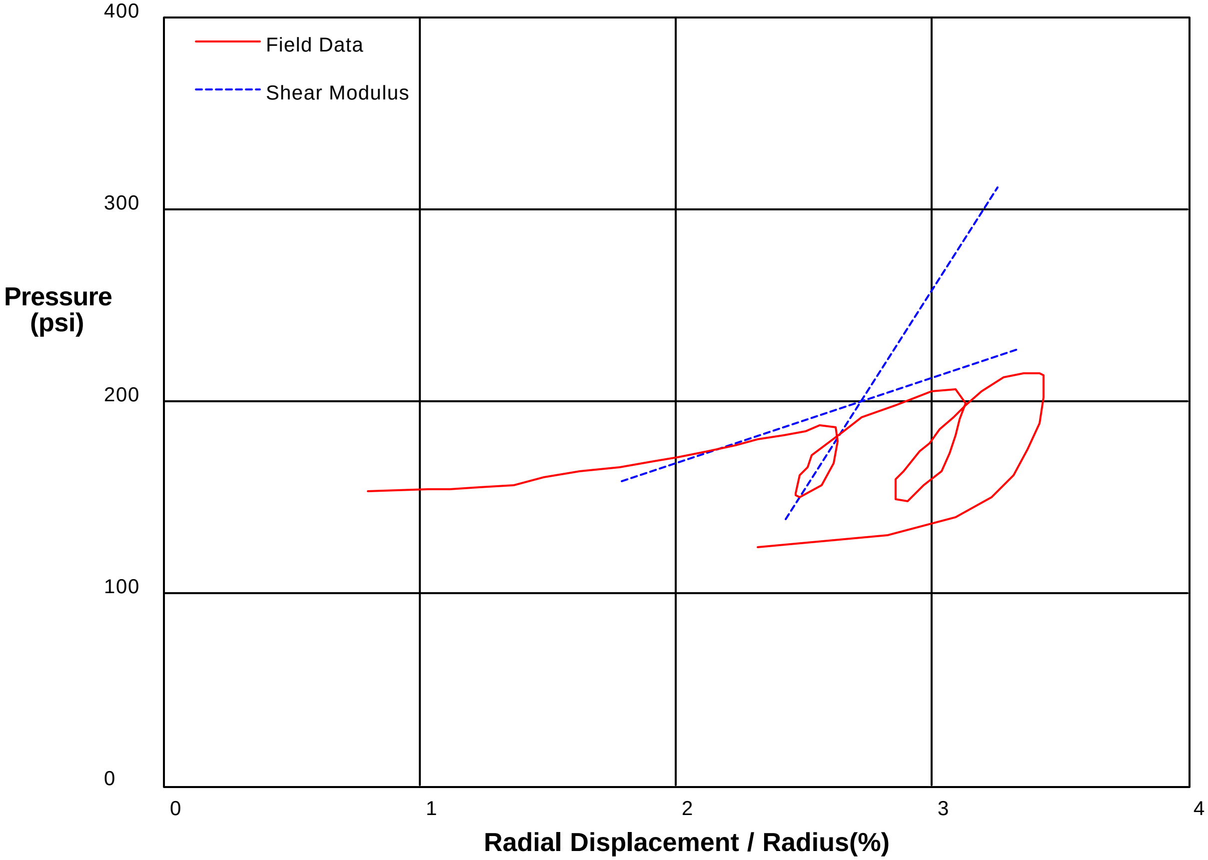
shift 10

HUGHES

PRESSUREMETER DATA Camp Dresser & McKee Inc.

King County Brightwater Project **May 21, 2003**

Hole No. E-207 **Depth 306 ft** **File C:\DATA\C-268\BW5.P**



Shear Modulus 2222 psi

Shear Modulus 10440 psi

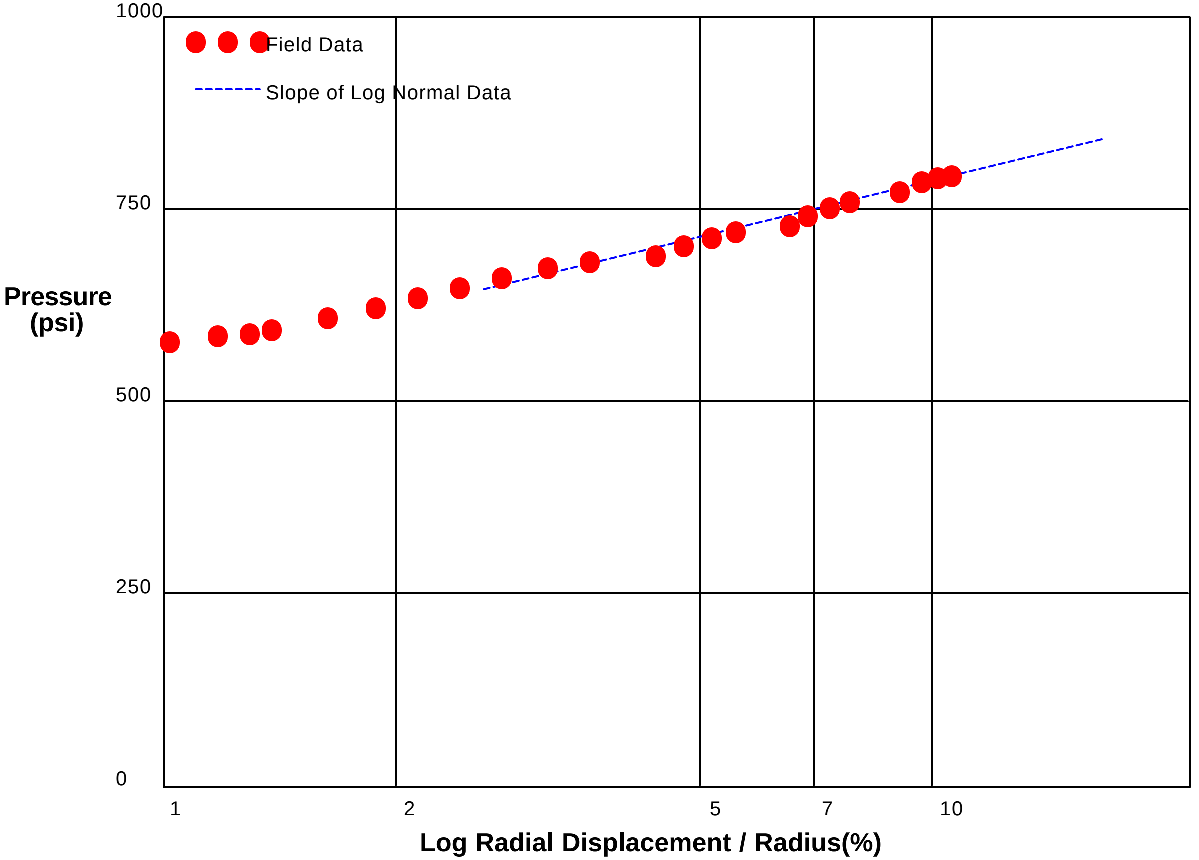
shift 8

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **May 13, 2003**

Hole No E-210 **Depth 207 ft** C:\DATA\C-268\BW2COM.P



Shear Strength	**105.9 psi**
Limit Pressure	**937 psi**

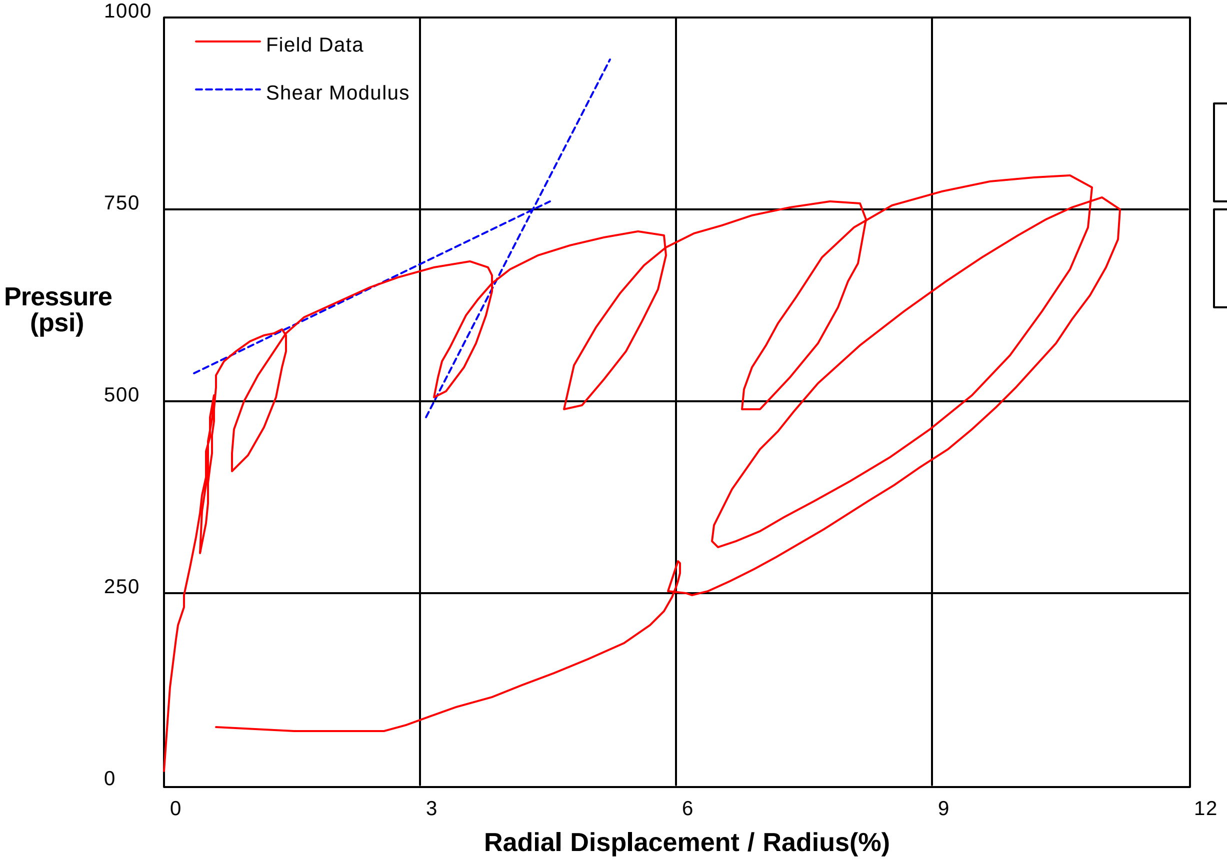
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **May 13, 2003**

Hole No. E-210 **Depth 207 ft** **File C:\DATA\C-268\BW2COM.P**



Shear Modulus 2684 psi

Shear Modulus 10751 psi

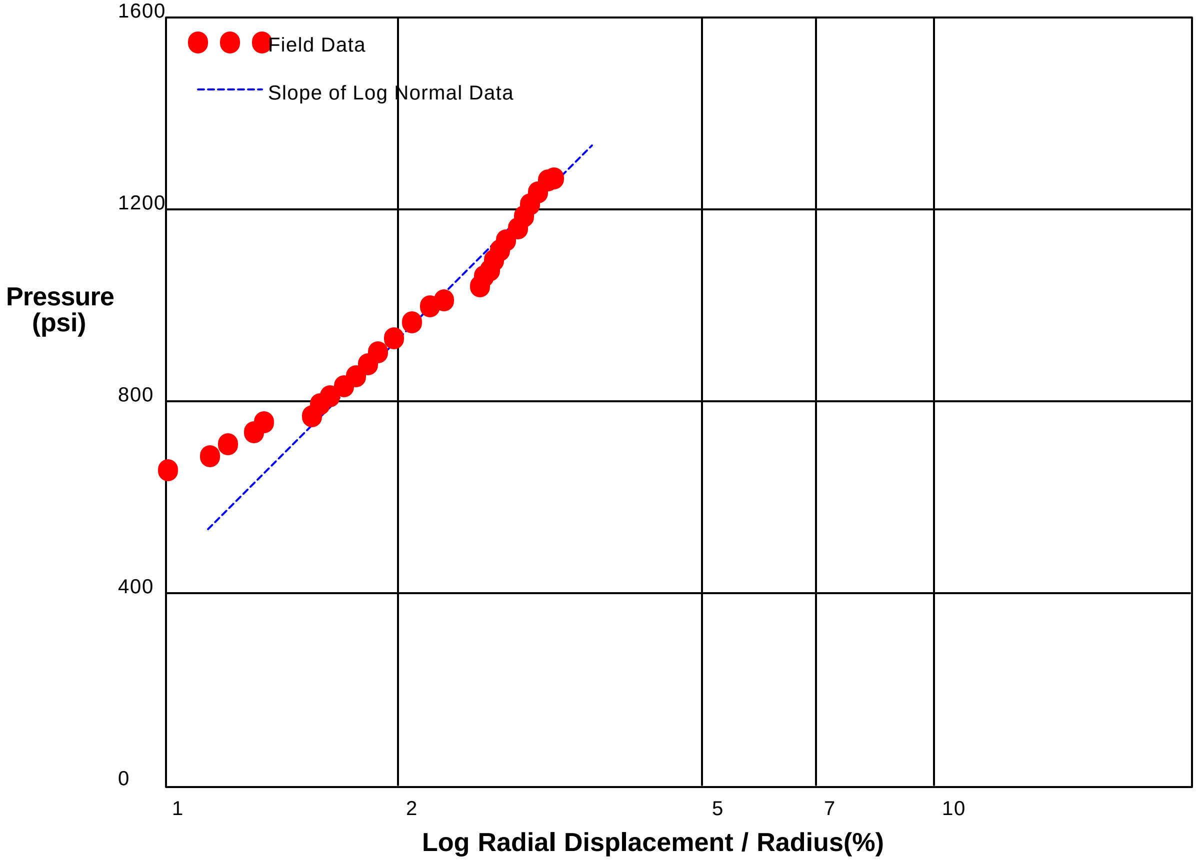
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 9, 2003**

Hole No E-211 **Depth 180** C:\DATA\C-268\BW14.P



Shear Strength	**694.8 psi**
Limit Pressure	**3024 psi**

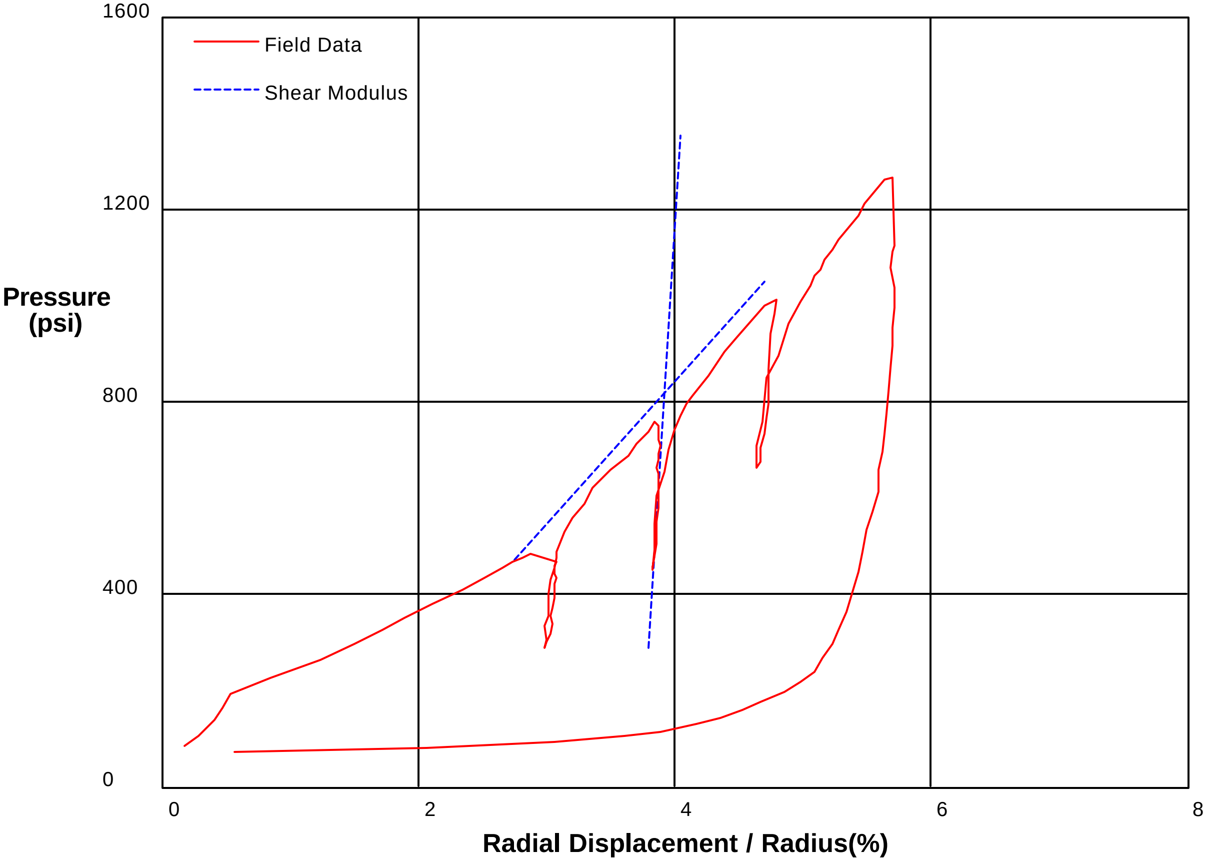
shift 2.5

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 9, 2003**

Hole No. E-211 **Depth 178.5 ft** **File C:\DATA\C-268\BW14.P**



Shear Modulus 14901 psi

Shear Modulus 213333 psi

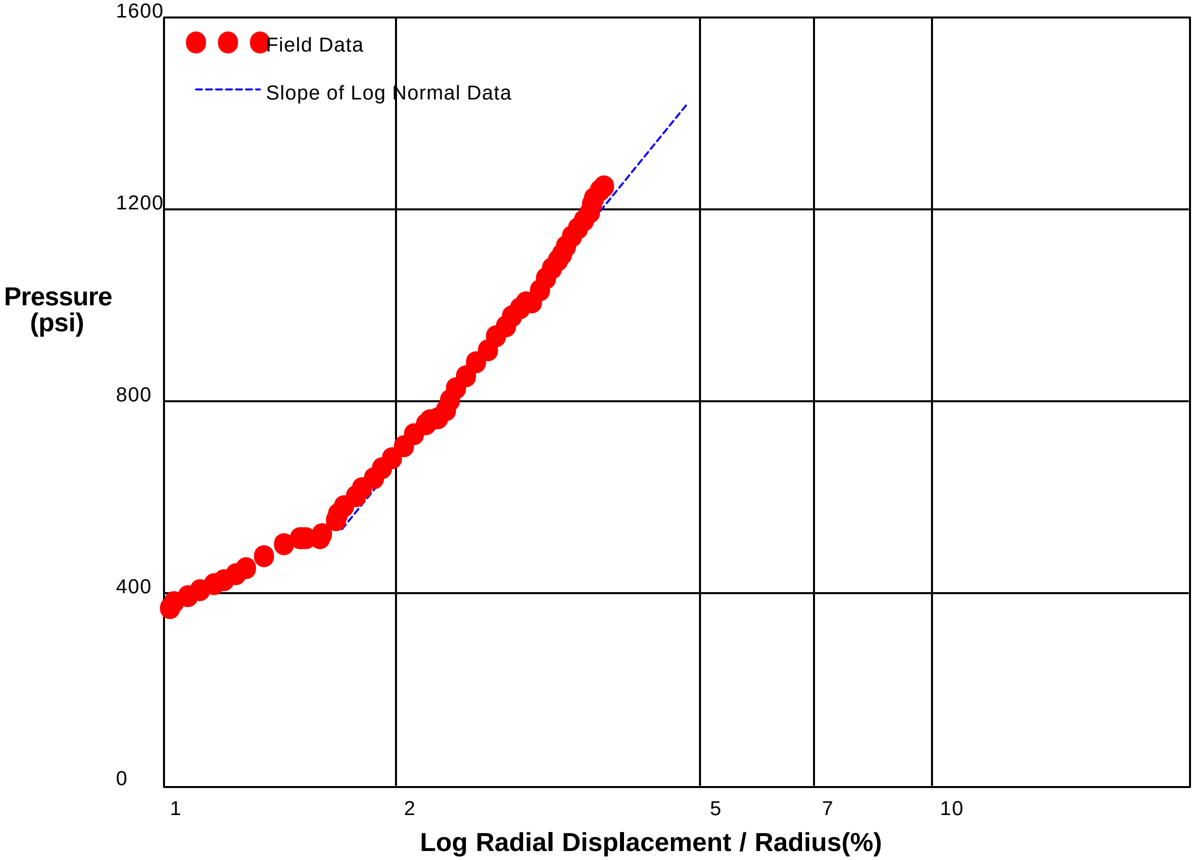
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 9, 2003**

Hole No E-211 **Depth 180 ft** C:\DATA\C-268\BW13.P



Shear Strength	**856.4 psi**
Limit Pressure	**3255 psi**

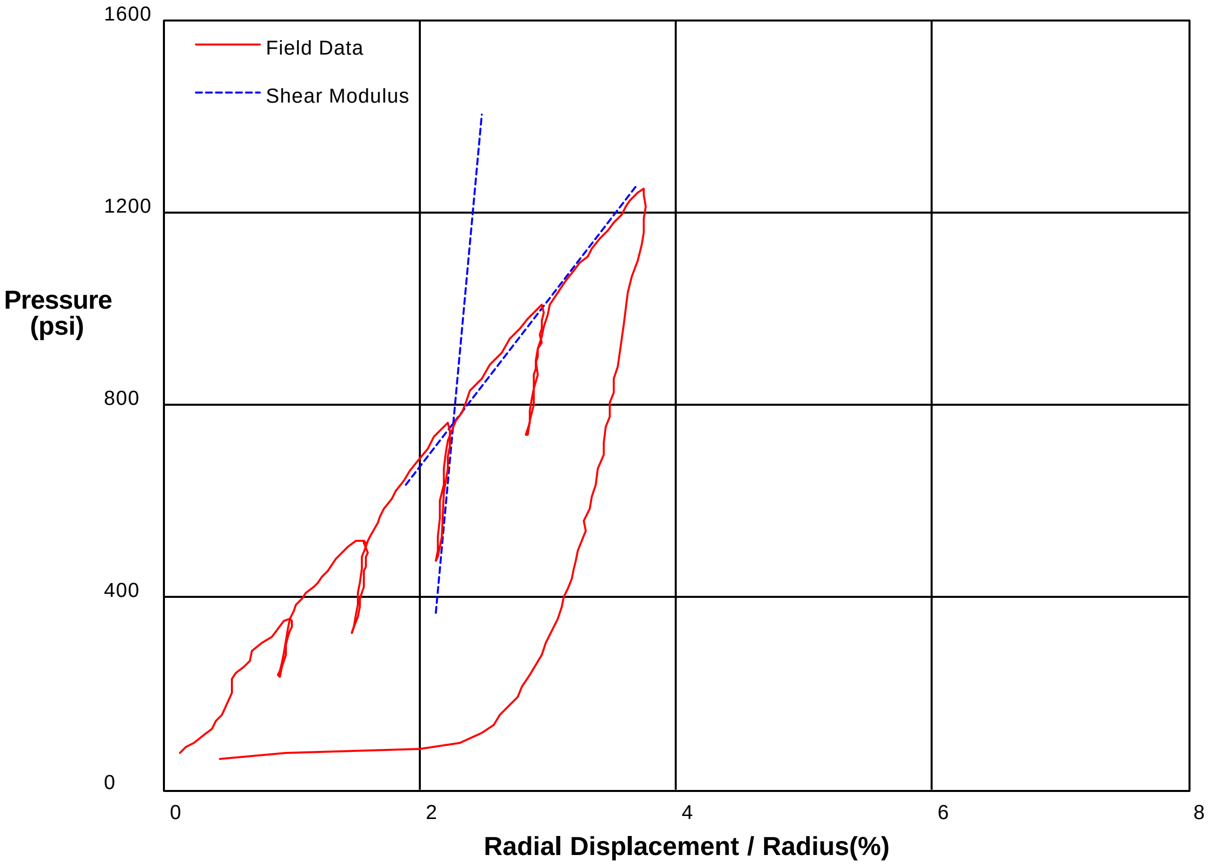
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 9, 2003**

Hole No. E-211 **Depth 180 ft** **File C:\DATA\C-268\BW13.P**



Shear Modulus 17364 psi

Shear Modulus 146666 psi

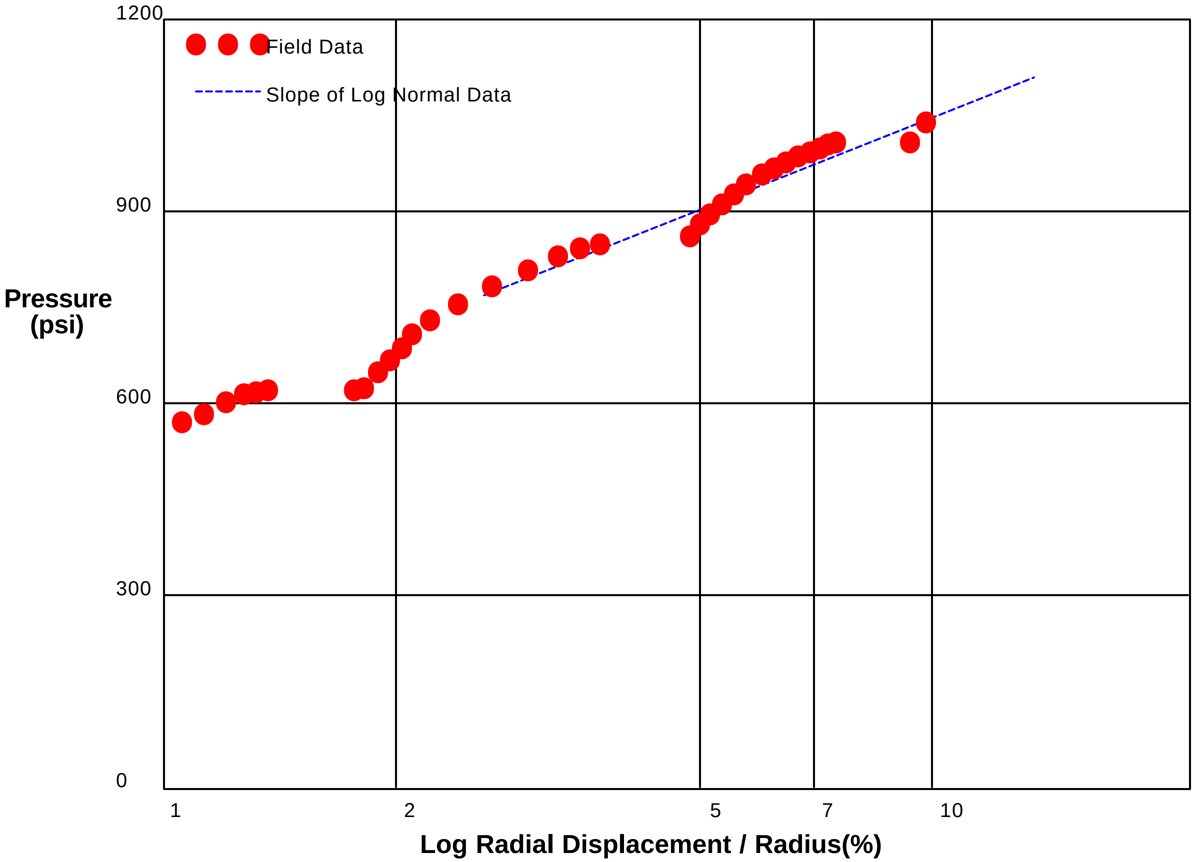
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 11, 2003**

Hole No E-211 **Depth 229.5 ft** C:\DATA\C-268\BW16.P



Shear Strength	**205.6 psi**
Limit Pressure	**1337 psi**

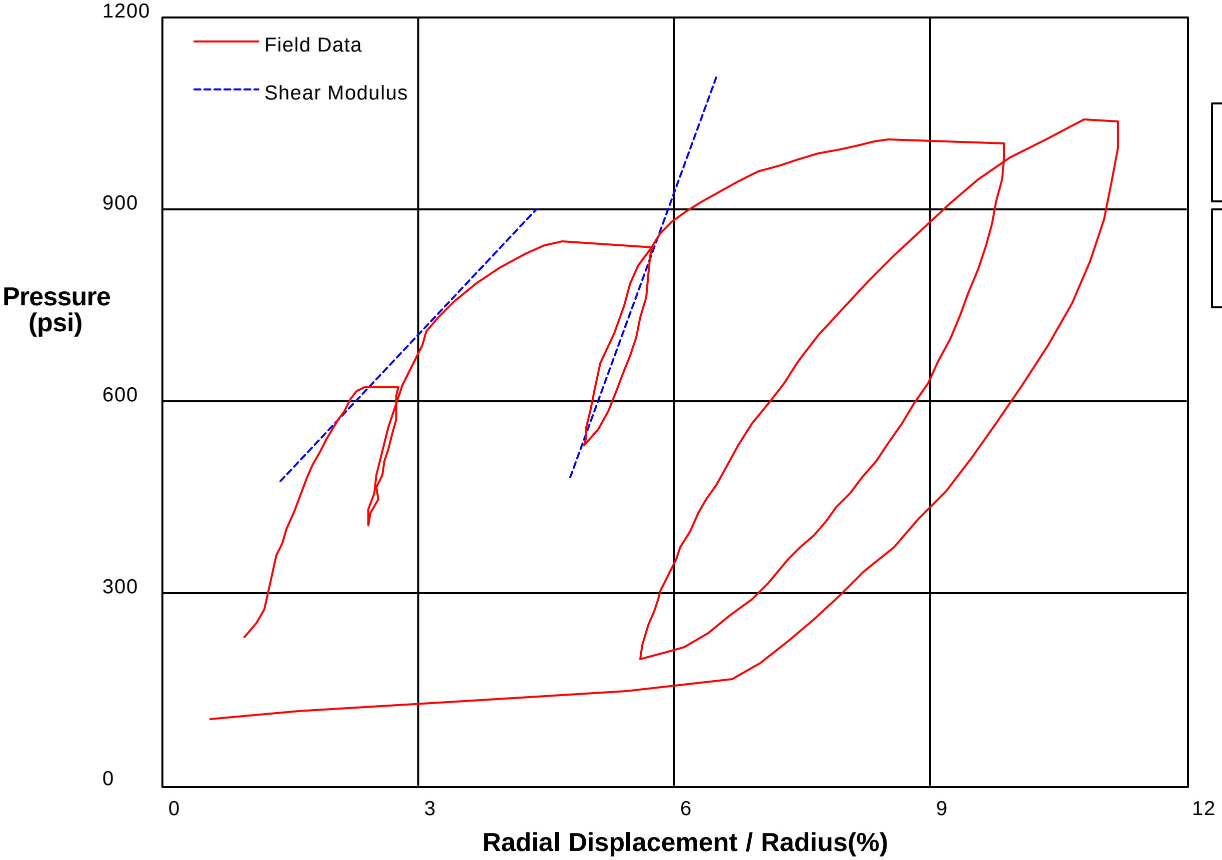
shift 1

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 11, 2003**

Hole No. E-211 **Depth 229.5 ft** **File C:\DATA\C-268\BW16.P**



Shear Modulus 7083 psi

Shear Modulus 18287 psi

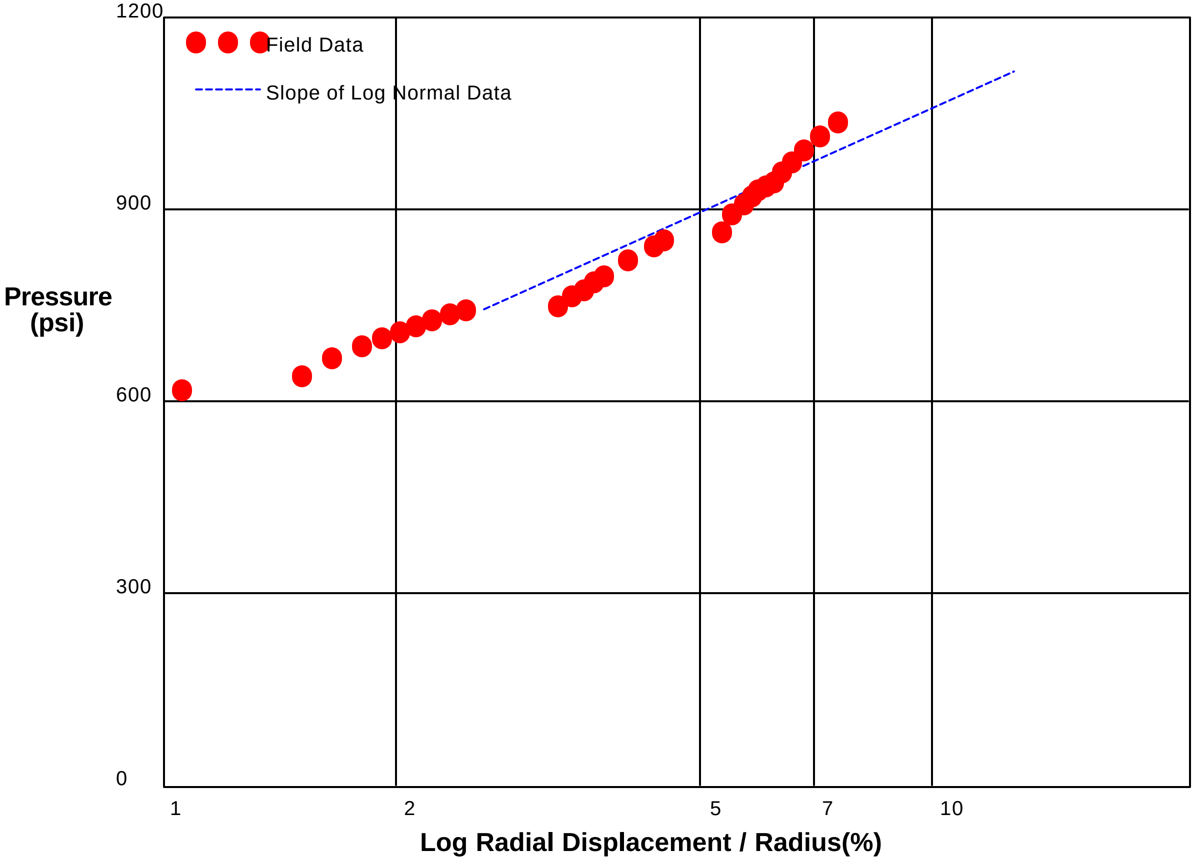
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 11, 2003**

Hole No E-211 **Depth 231 ft** C:\DATA\C-268\BW15.P



Shear Strength	**233 psi**
Limit Pressure	**1387 psi**

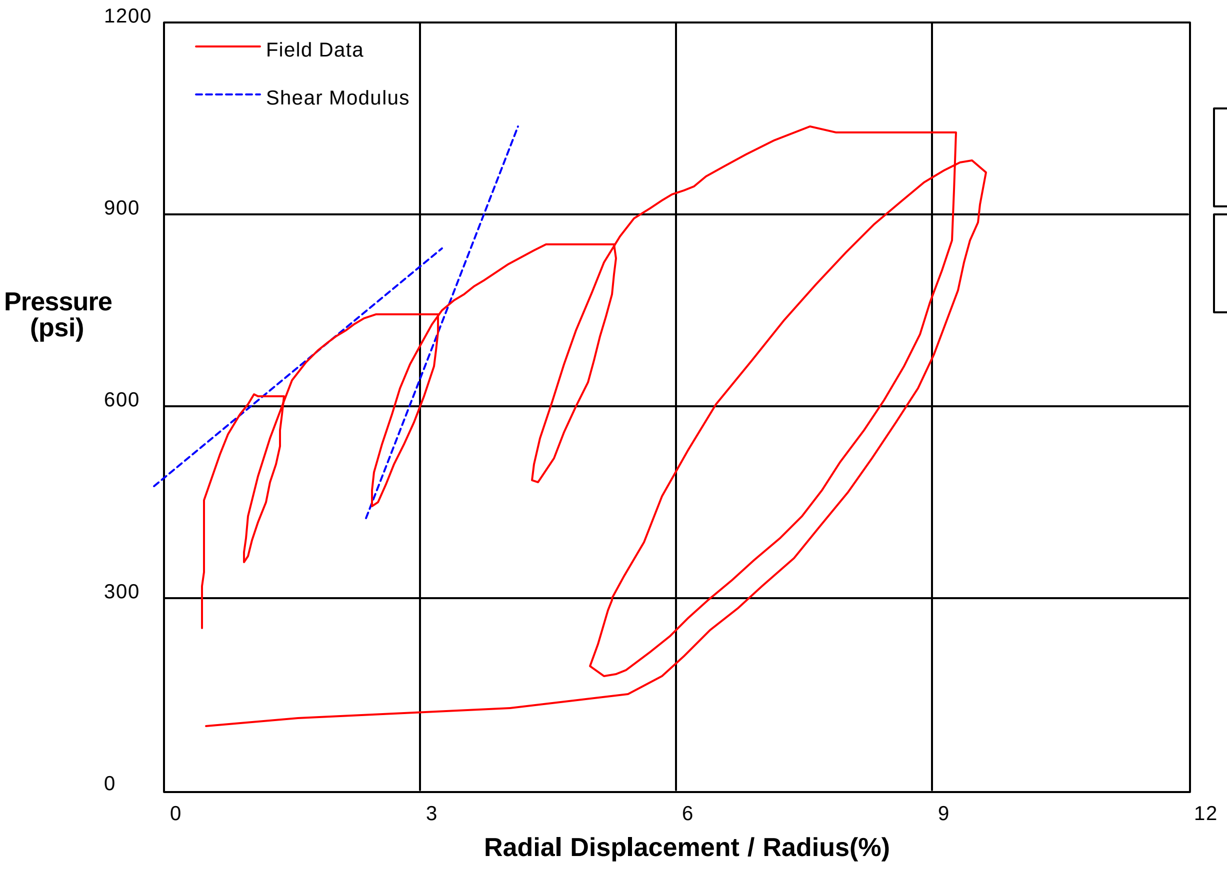
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 11, 2003**

Hole No. E-211 **Depth 231 ft** **File C:\DATA\C-268\BW15.P**



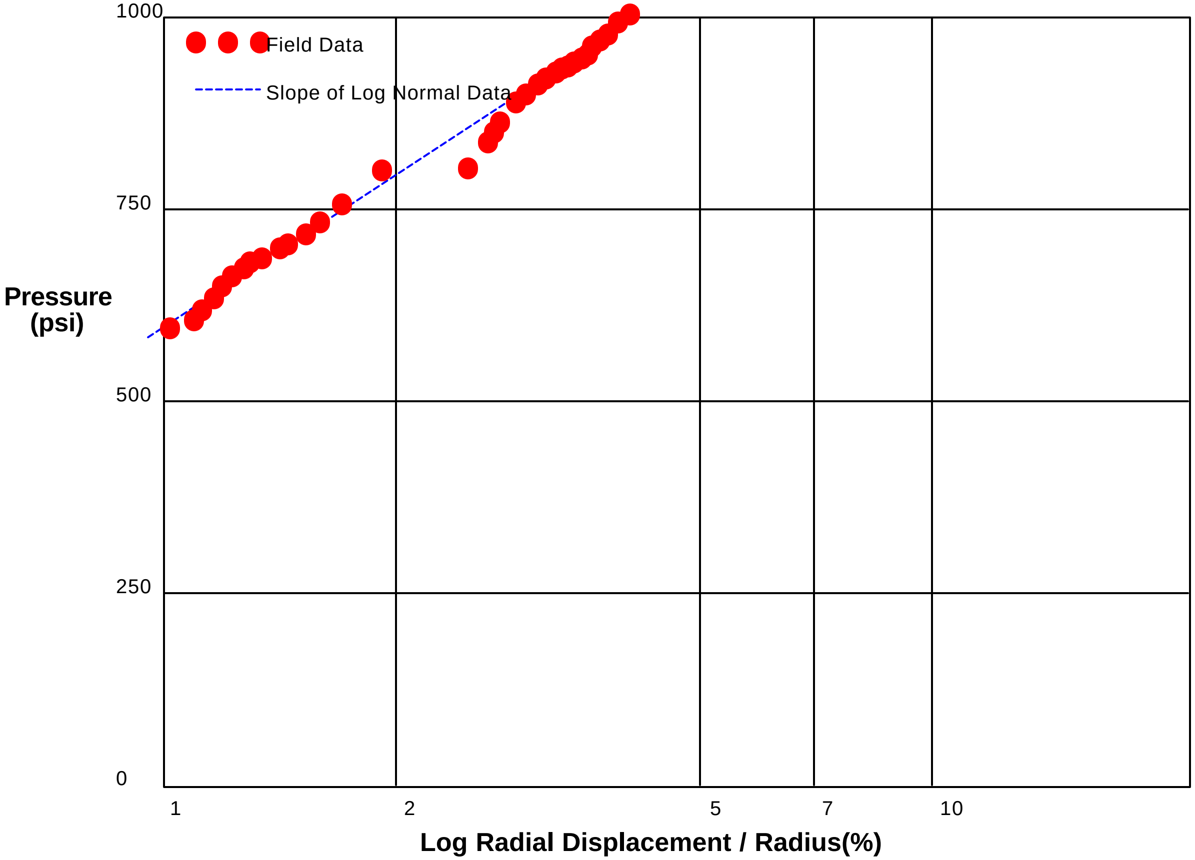
Shear Modulus 5499 psi

Shear Modulus 17192 psi

shift 0

HUGHES

PRESSUREMETER DATA	**Camp Dresser & McKee Inc.**	
King County Brightwater Project		**July 17, 2003**
Hole No E-214	**Depth 284.5 ft**	C:\DATA\C-268\BW29X.P



Shear Strength	**284.5 psi**
Limit Pressure	**1653 psi**

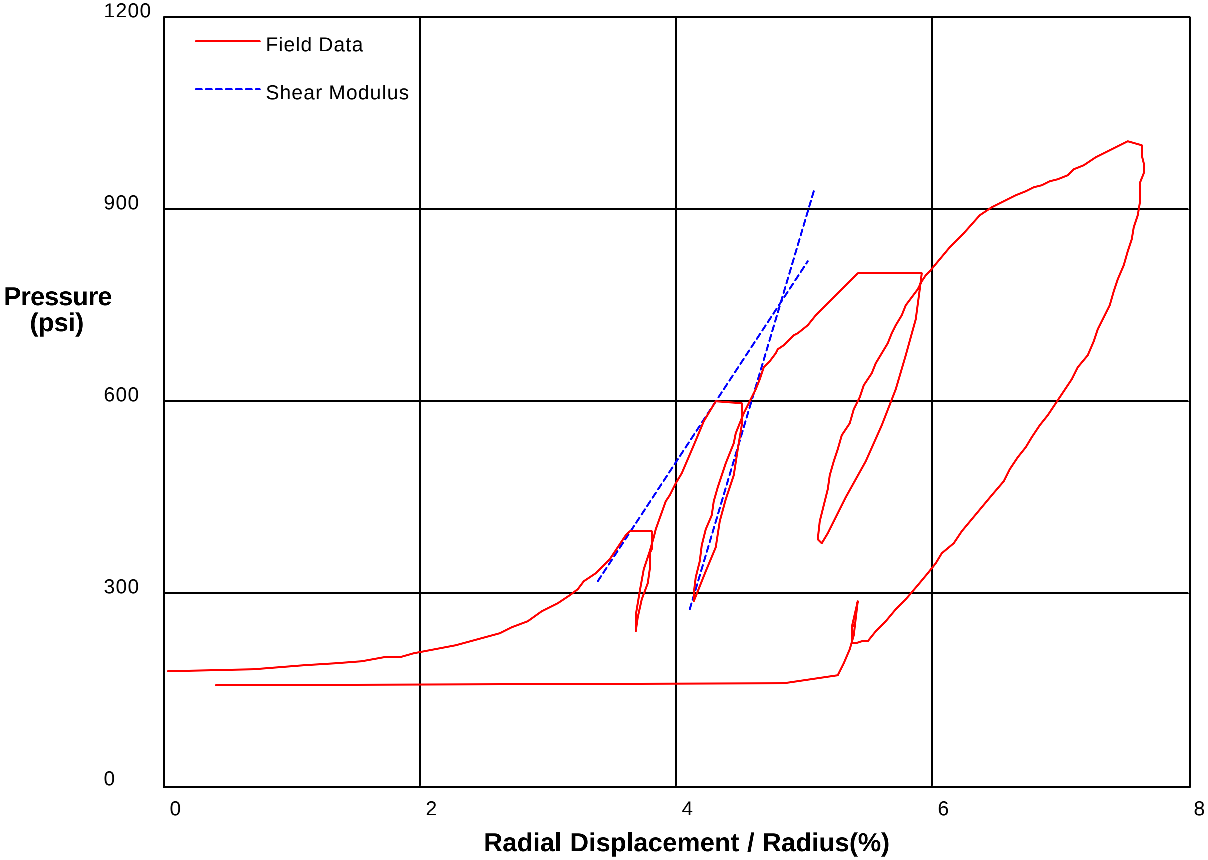
shift 7.5

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 17, 2003**

Hole No. E-214 **Depth 284.5 ft** **File C:\DATA\C-268\BW29X.P**



Shear Modulus 15222 psi

Shear Modulus 33404 psi

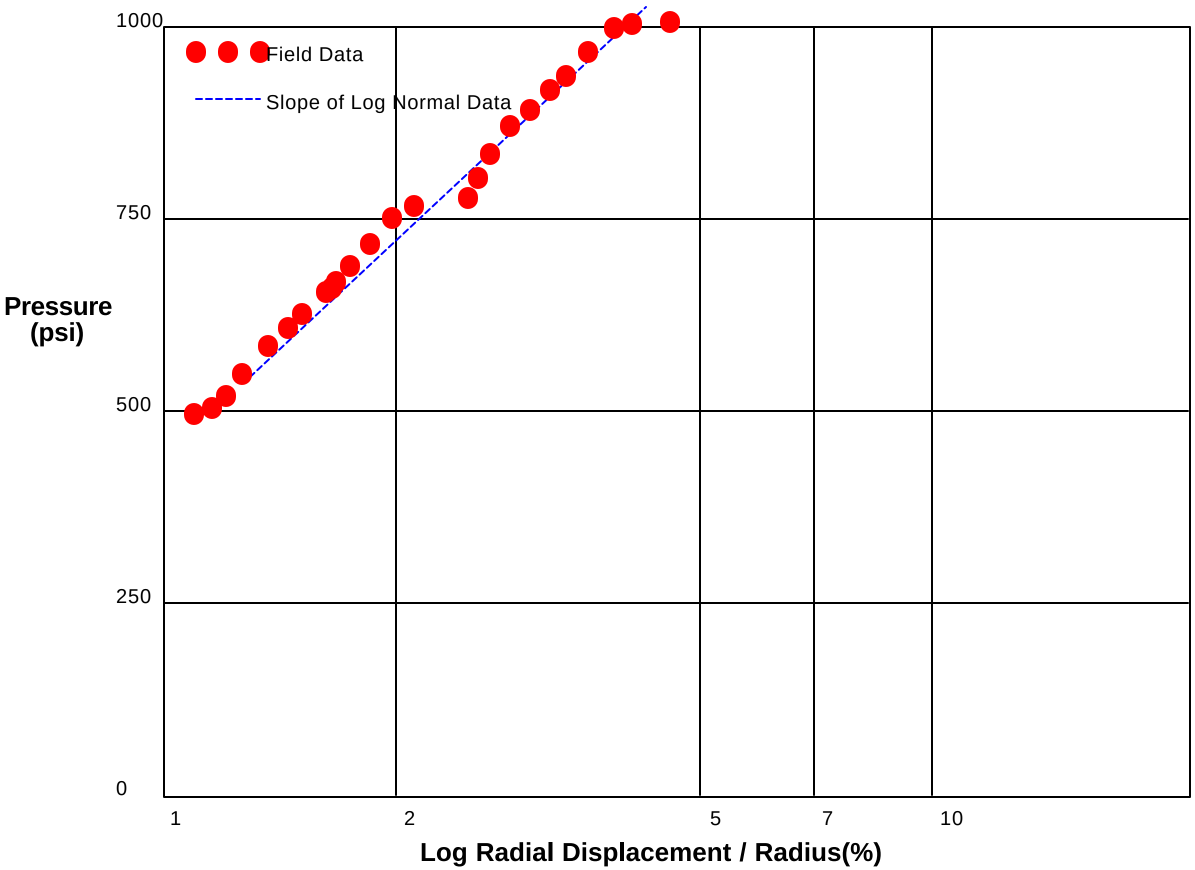
shift 4

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 17, 2003**

Hole No E-214 **Depth 286 ft** C:\DATA\C-268\BW28.P



Shear Strength	**405.1 psi**
Limit Pressure	**1946 psi**

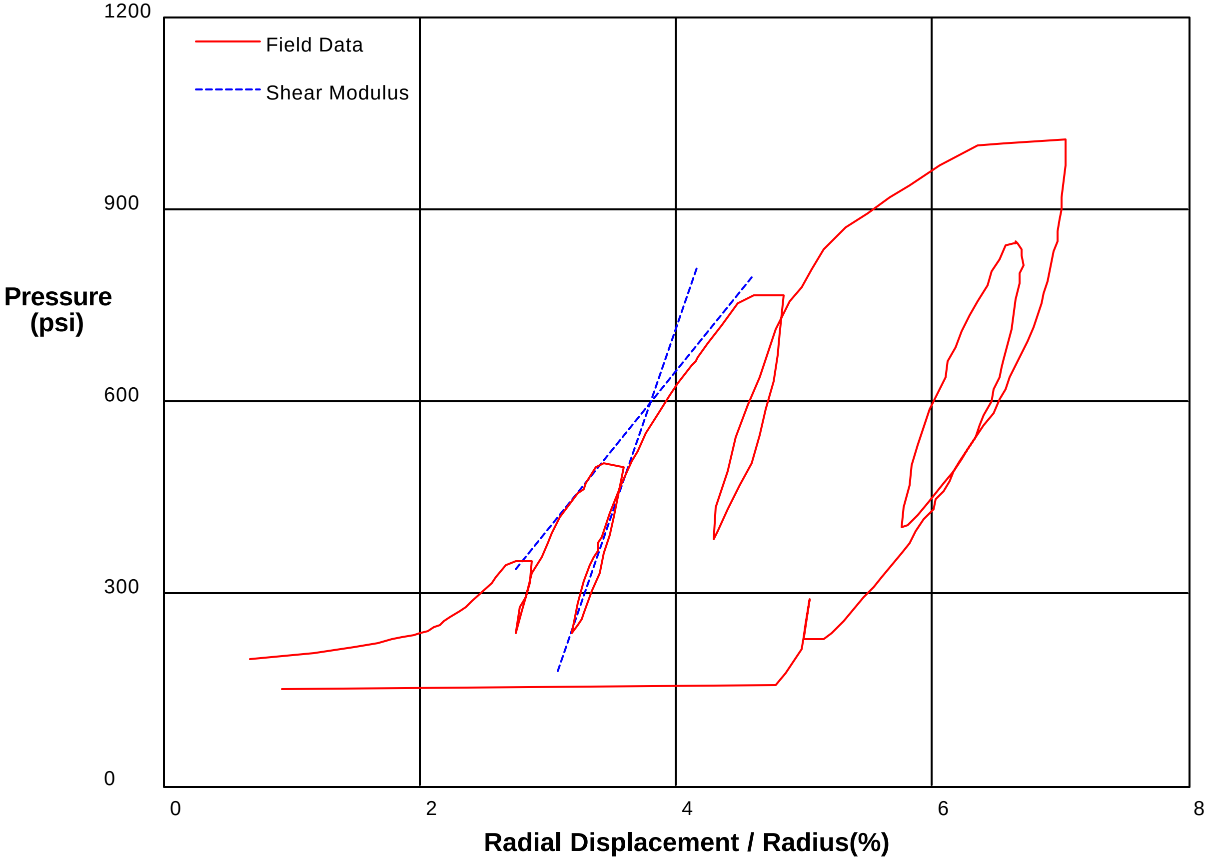
shift 3.5

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 17, 2003**

Hole No. E-214 **Depth 286 ft** **File C:\DATA\C-268\BW28.P**



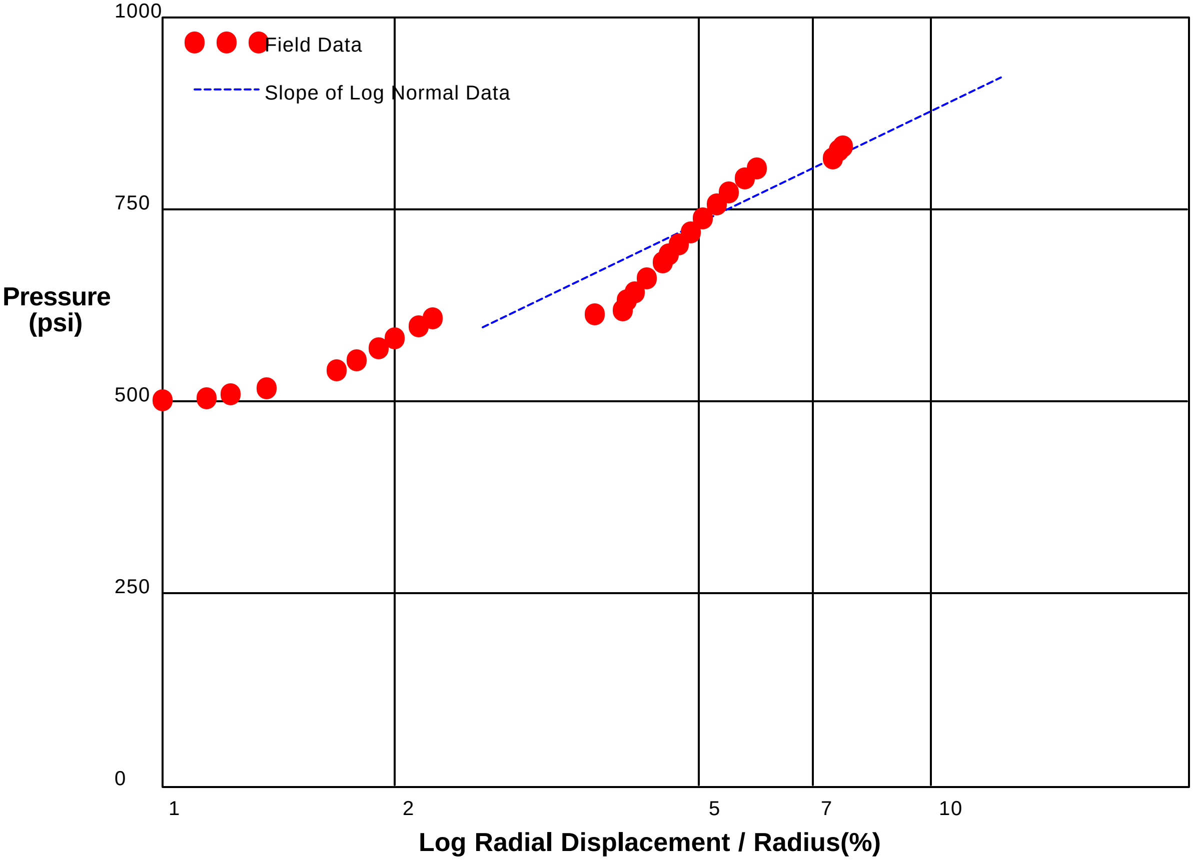
Shear Modulus 12372 psi

Shear Modulus 29230 psi

shift 1

HUGHES

PRESSUREMETER DATA	**Camp Dresser & McKee Inc.**	
King County Brightwater Project		**July 18, 2003**
Hole No E-214	**Depth 318.5 ft**	C:\DATA\C-268\BW31.P



Shear Strength	**210.4 psi**
Limit Pressure	**1176 psi**

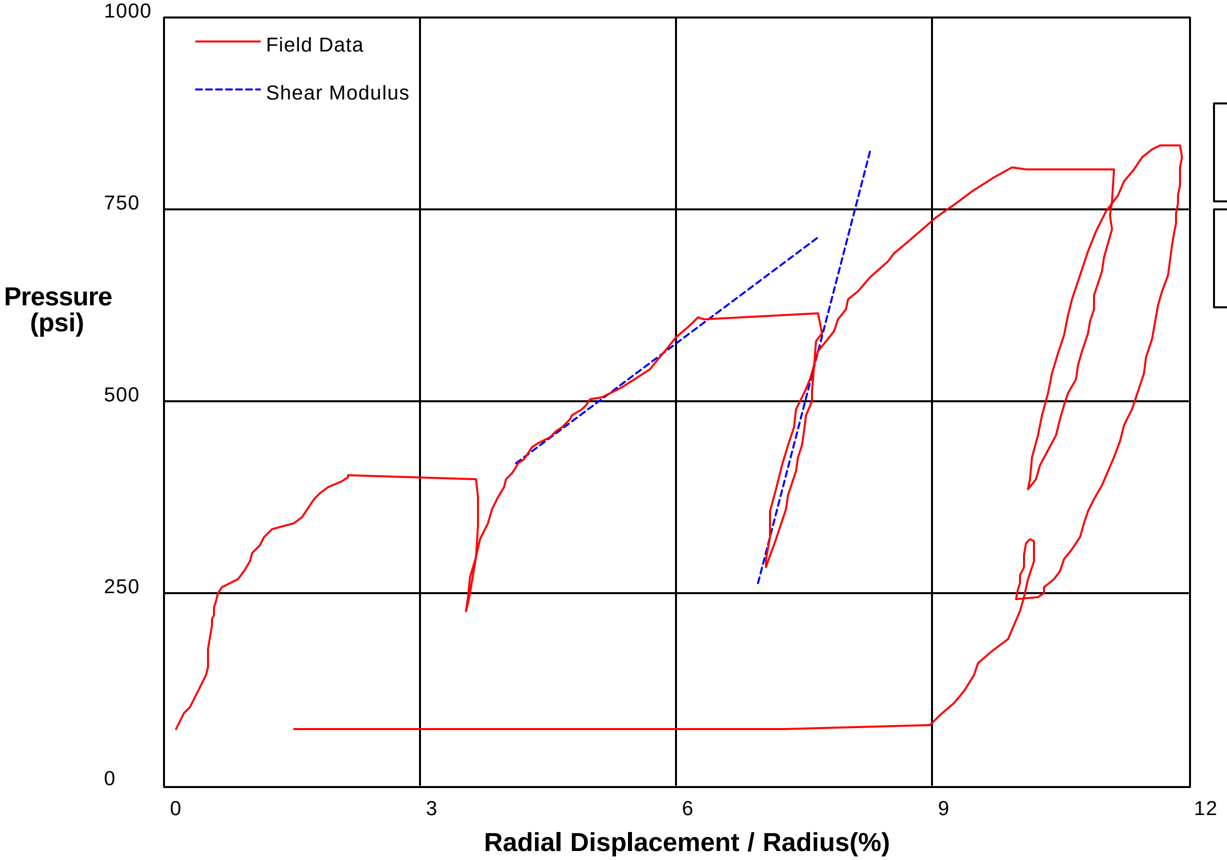
shift 4

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 18, 2003**

Hole No. E-214 **Depth 318.5 ft** **File C:\DATA\C-268\BW31.P**



Shear Modulus 4136 psi

Shear Modulus 21428 psi

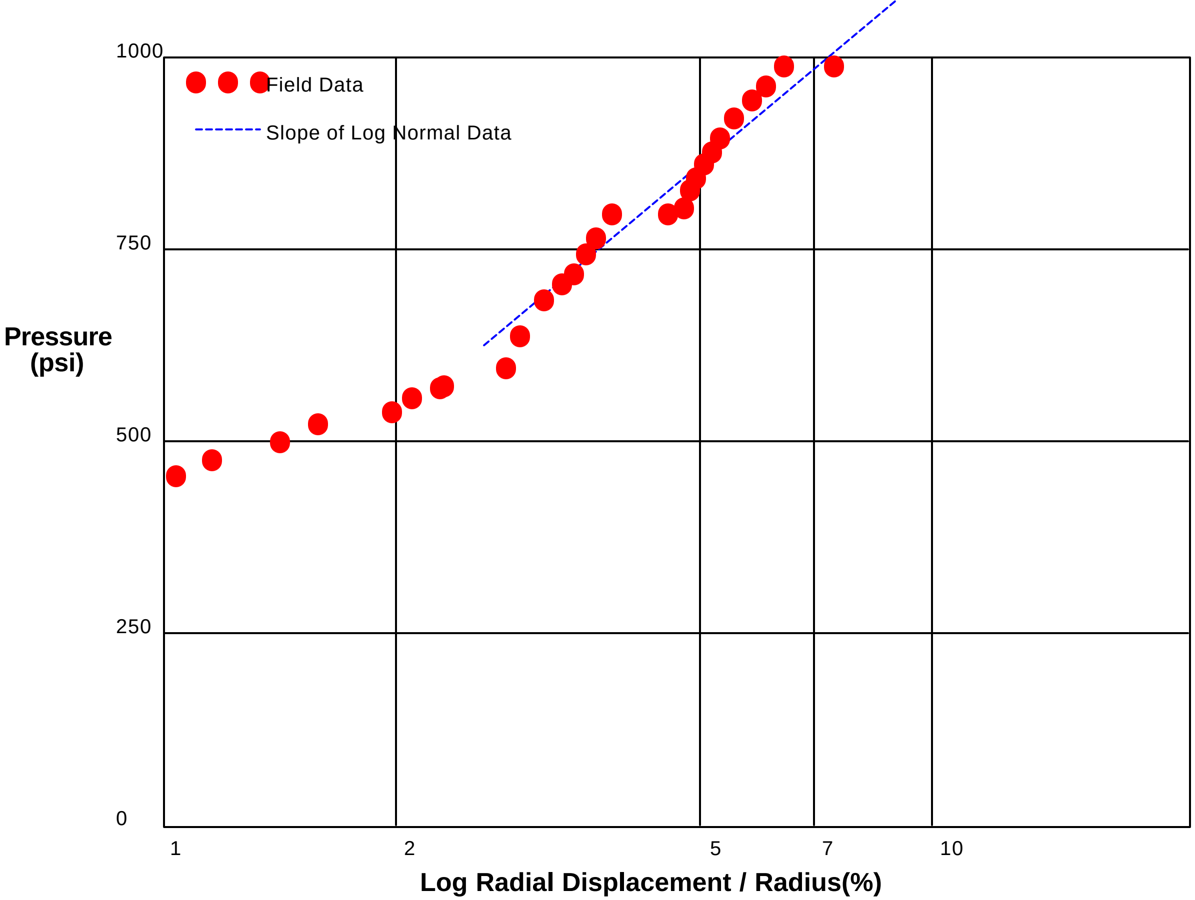
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 18, 2003**

Hole No E-214 **Depth 320 ft** C:\DATA\C-268\BW30.P



Shear Strength	**364.9 psi**
Limit Pressure	**1630 psi**

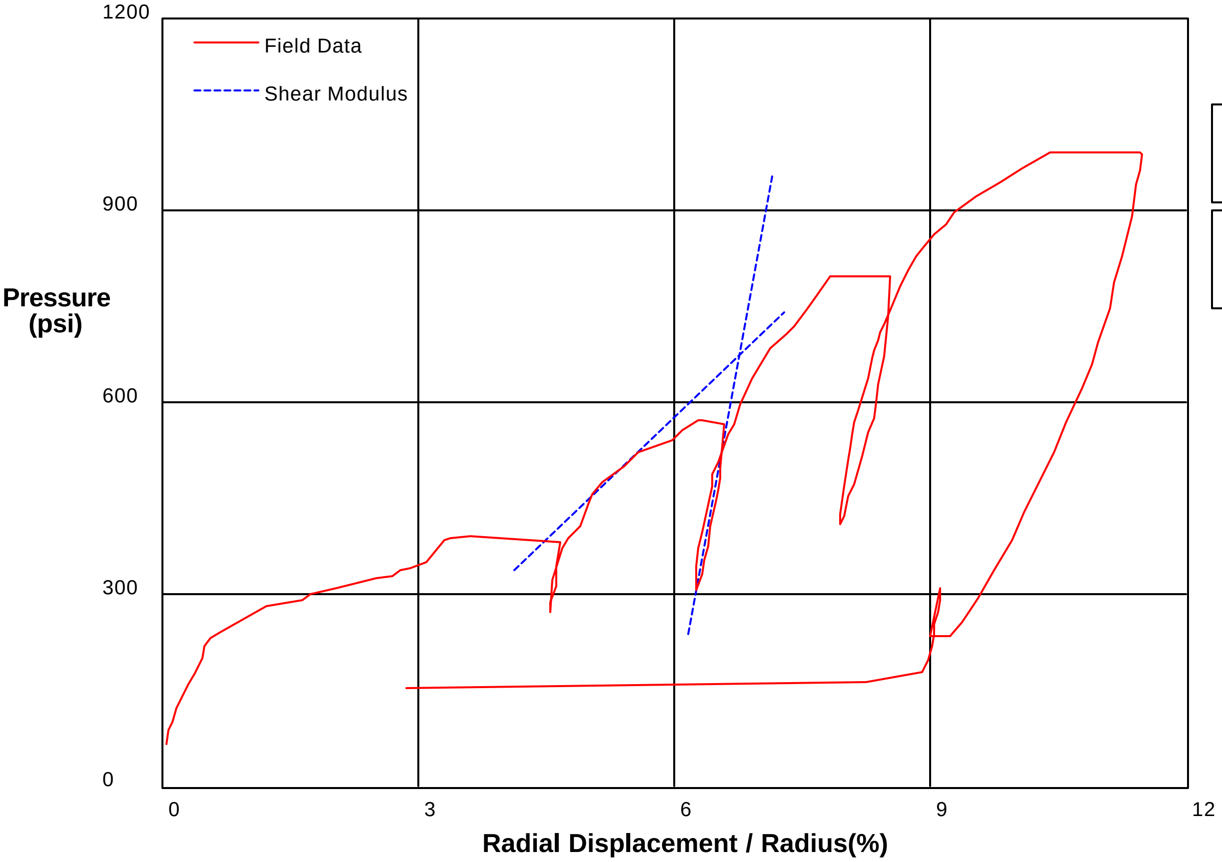
shift 4

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 18, 2003**

Hole No. E-214 **Depth 320 ft** **File C:\DATA\C-268\BW30.P**



Shear Modulus 6402 psi

Shear Modulus 35833 psi

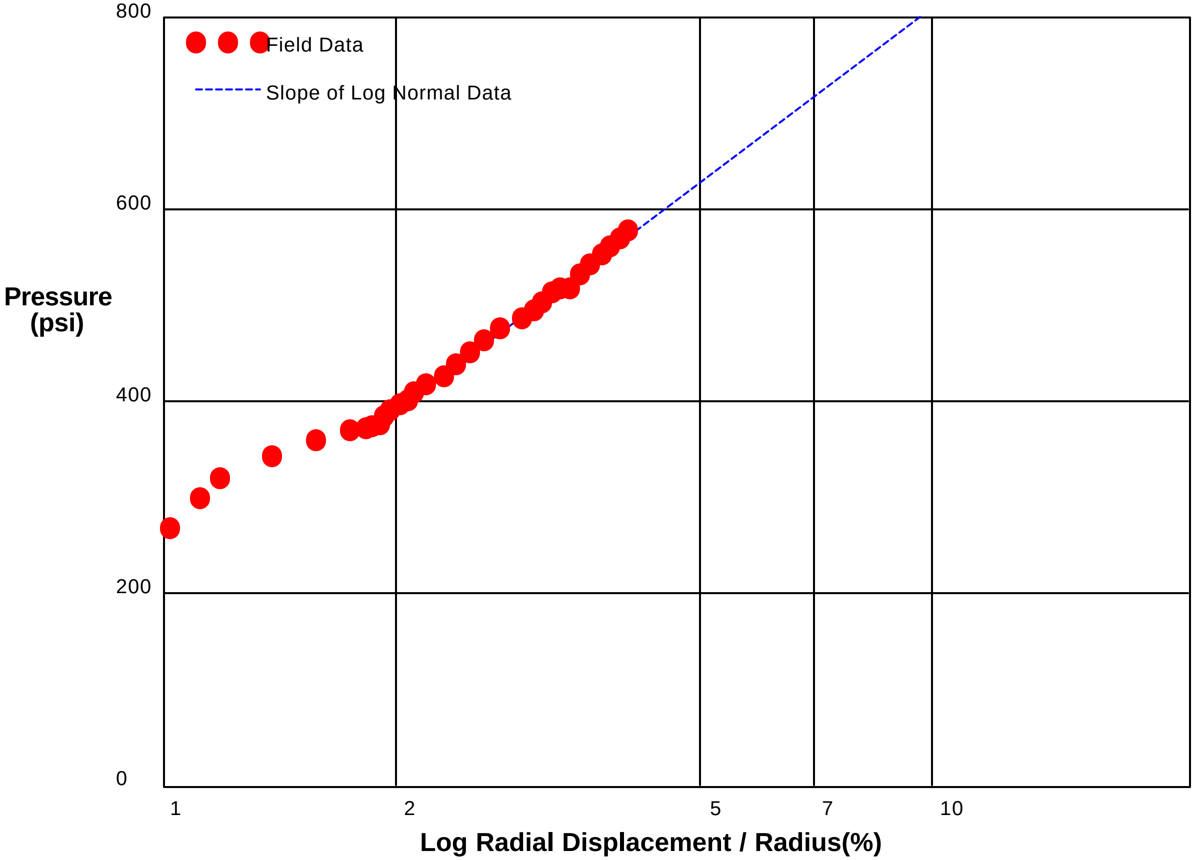
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 3, 2003**

Hole No E-223 **Depth 143 ft** C:\DATA\C-268\BW7.P



Shear Strength	**262.6 psi**
Limit Pressure	**1181 psi**

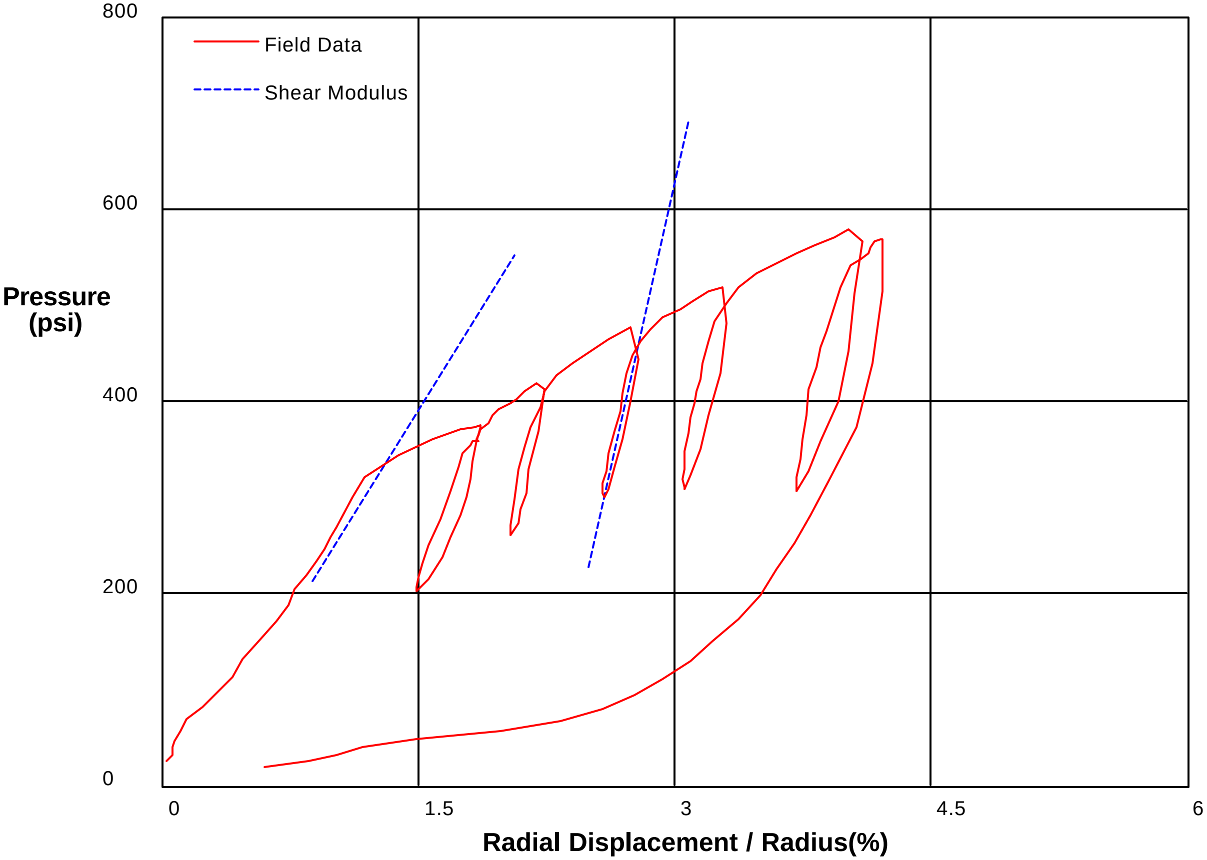
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 3, 2003**

Hole No. E-223 **Depth 143 ft** **File C:\DATA\C-268\BW7.P**



Shear Modulus 14269 psi

Shear Modulus 40120 psi

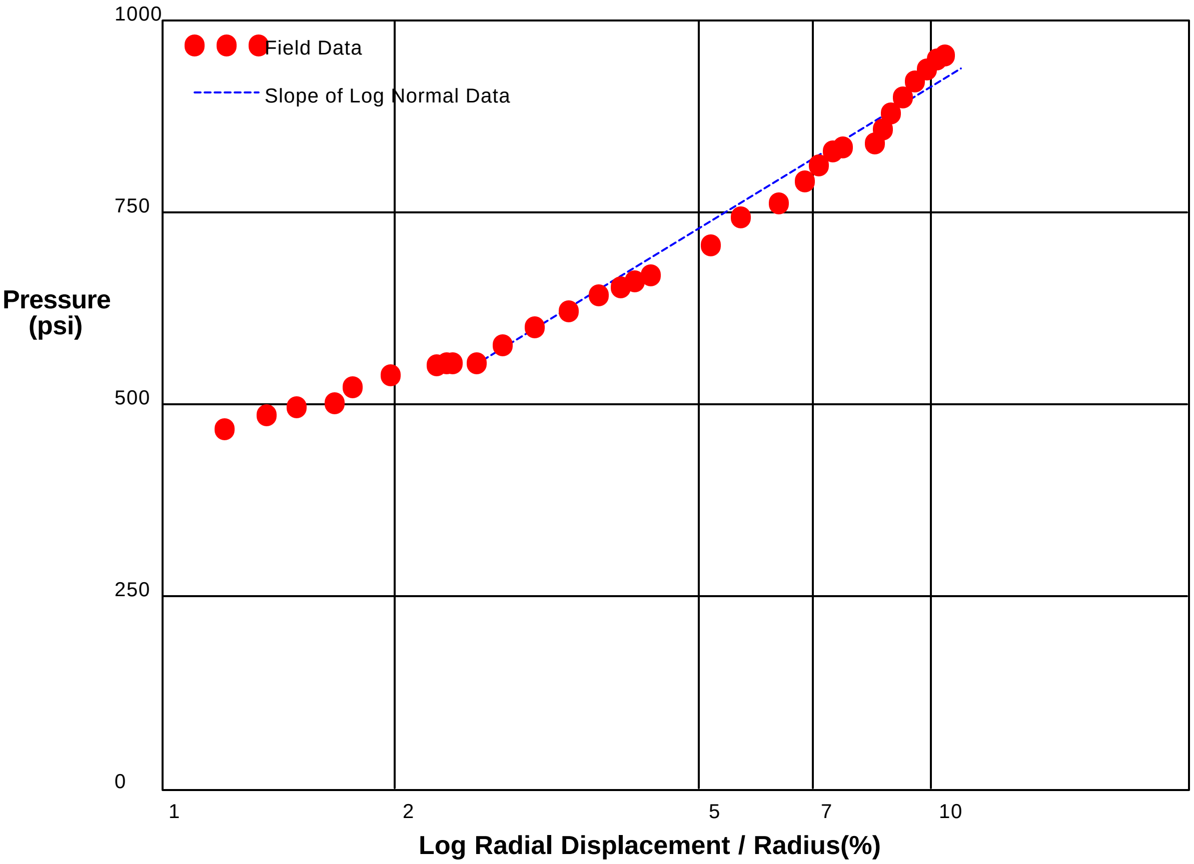
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 4, 2003**

Hole No E-223 **Depth 178.5 ft** C:\DATA\C-268\BW10.P



Shear Strength	**264.4 psi**
Limit Pressure	**1287 psi**

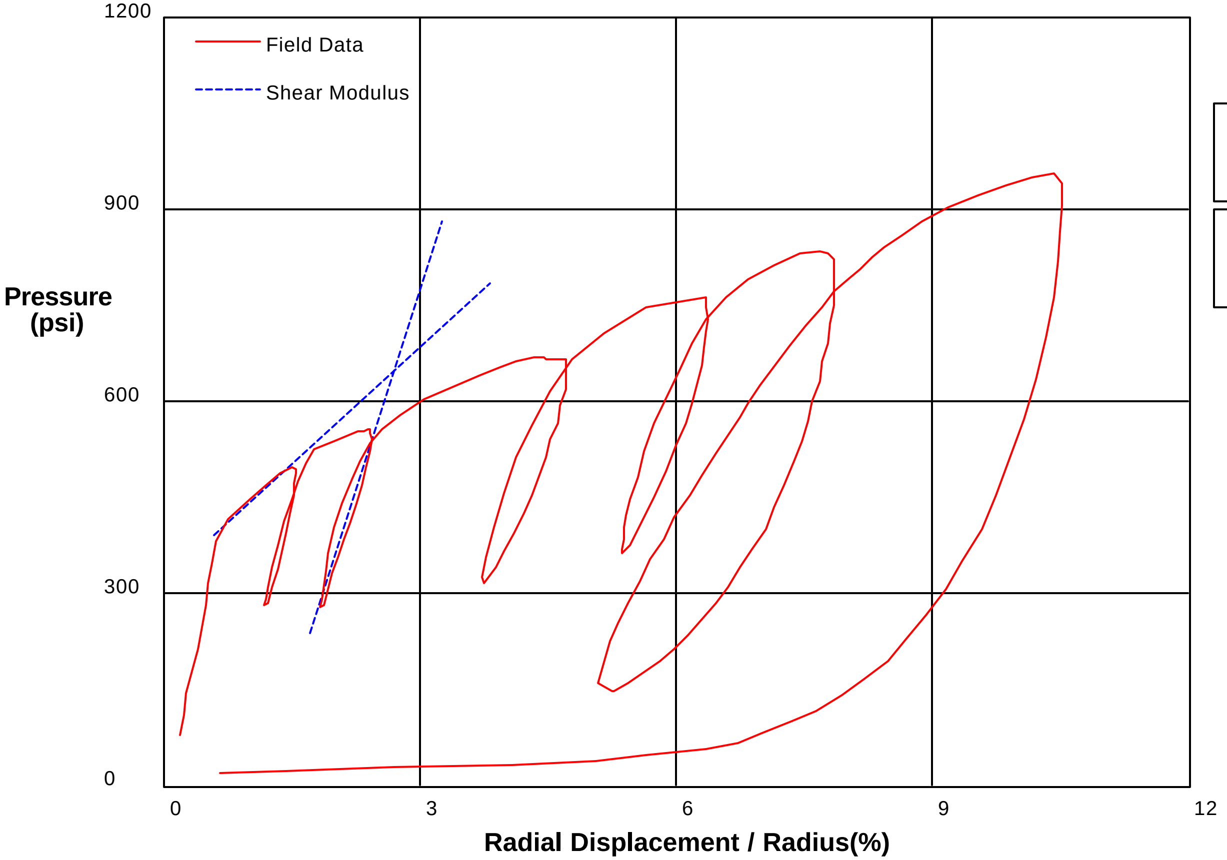
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 4, 2003**

Hole No. E-223 **Depth 178.5 ft** **File C:\DATA\C-268\BW10.P**



Shear Modulus 6086 psi

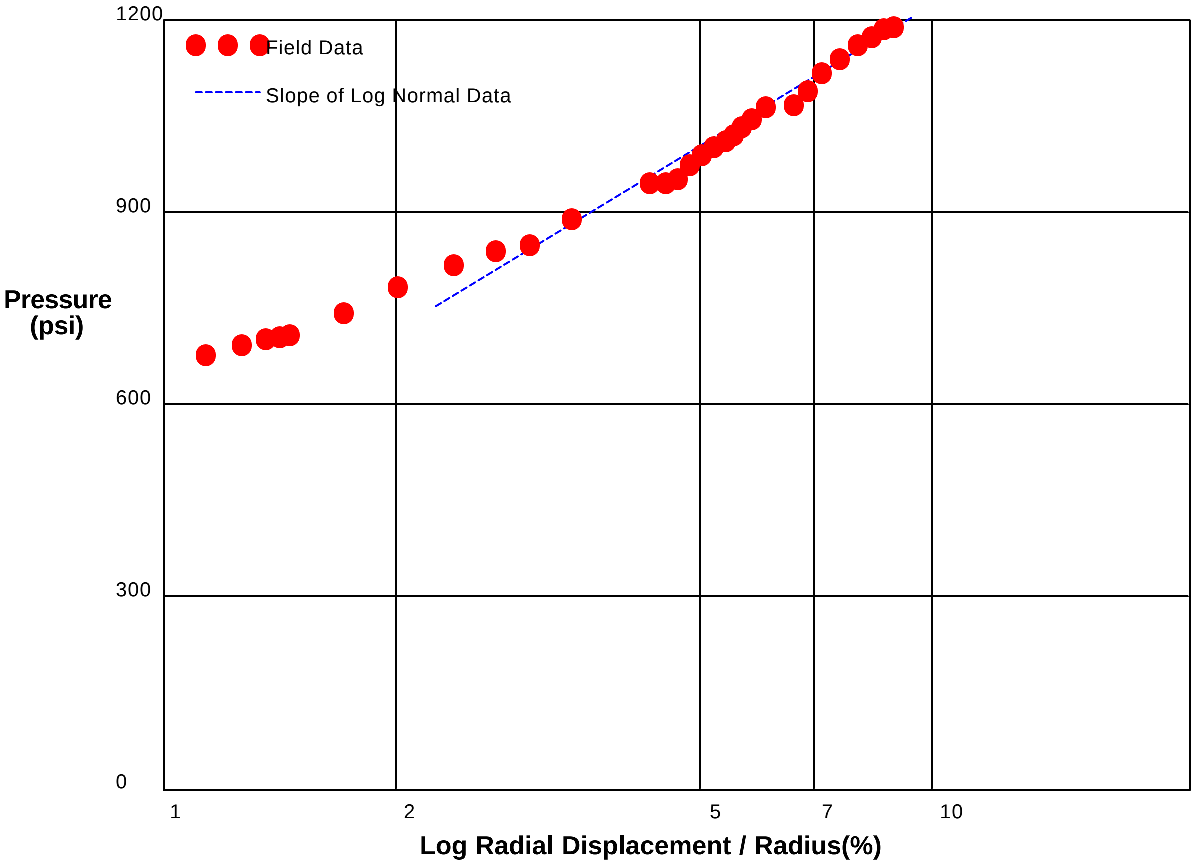
Shear Modulus 20808 psi

shift 0

HUGHES

PRESSUREMETER DATA Camp Dresser & McKee Inc.

King County Brightwater Project **June 4, 2003**
Hole No E-223 **Depth 180 ft** C:\DATA\C-268\BW9.P



Shear Strength	**317.3 psi**
Limit Pressure	**1673 psi**

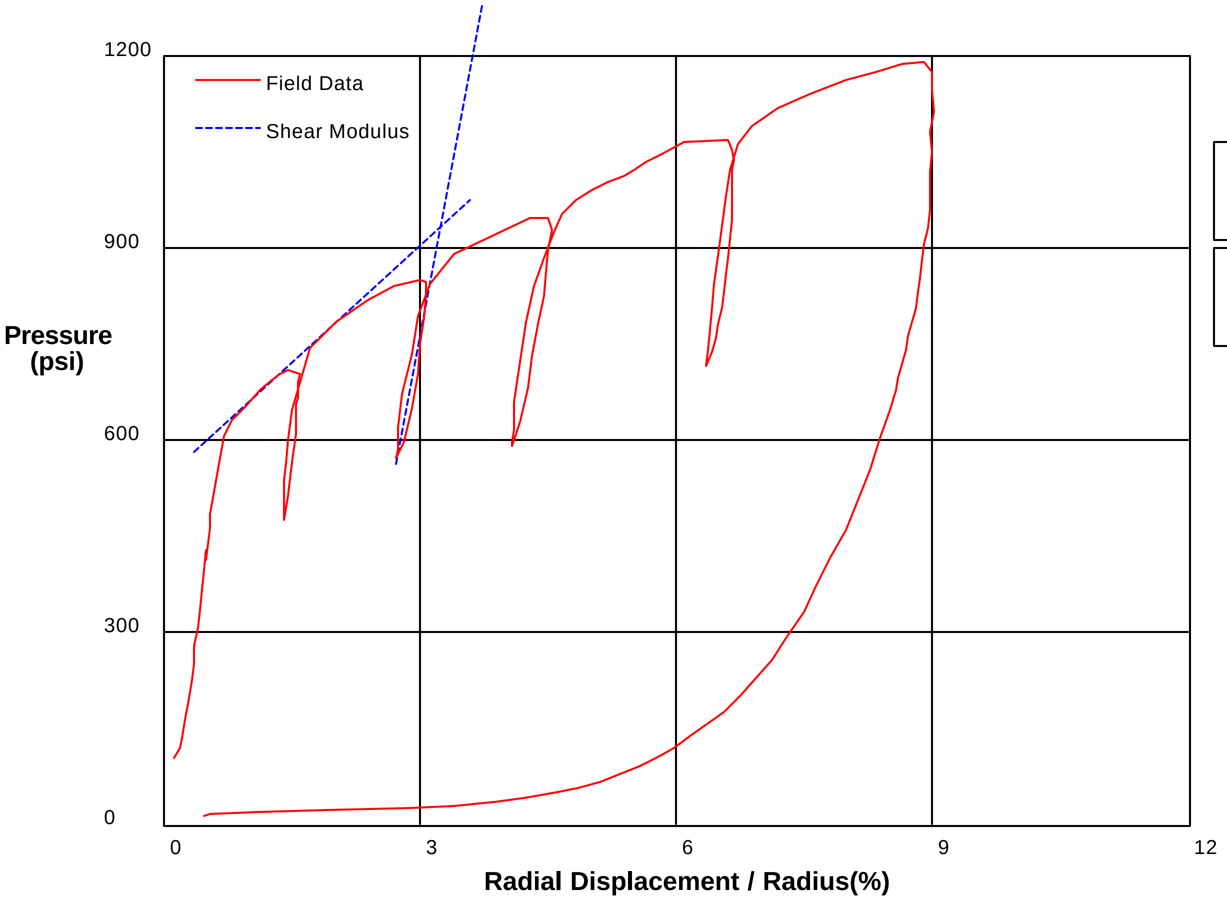
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 4, 2003**

Hole No. E-223 **Depth 180 ft** **File C:\DATA\C-268\BW9.P**



Shear Modulus 6086 psi

Shear Modulus 35833 psi

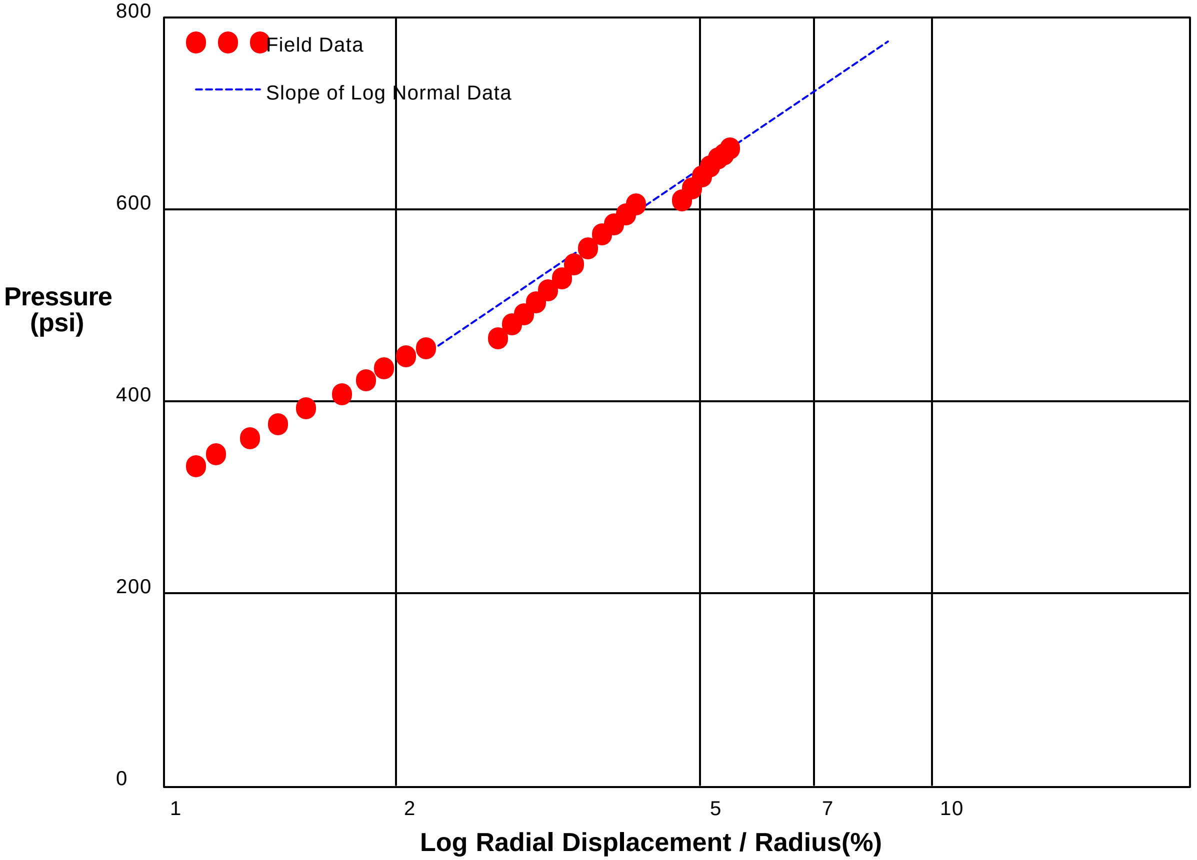
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 5, 2003**

Hole No E-223 **Depth 288.5 ft** C:\DATA\C-268\BW12.P



Shear Strength	**236 psi**
Limit Pressure	**1140 psi**

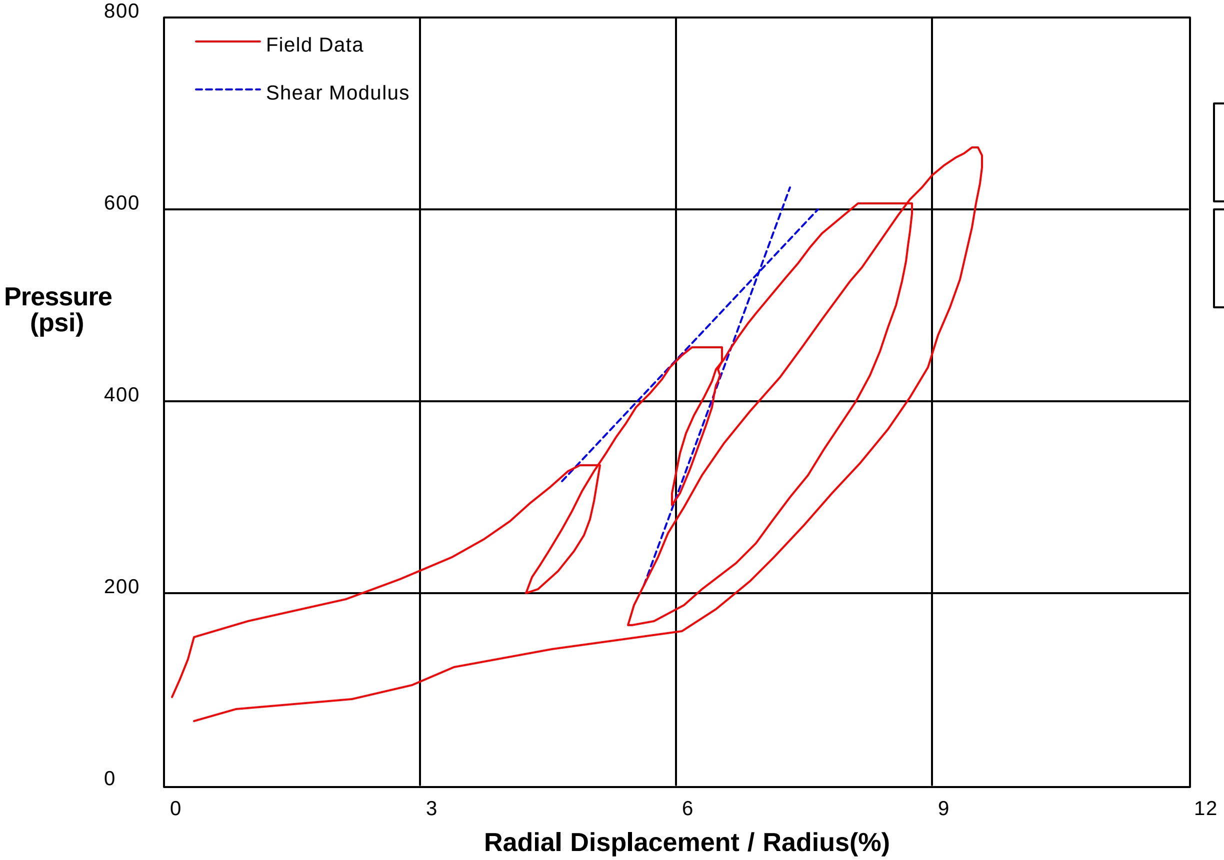
shift 4

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 5, 2003**

Hole No. E-223 **Depth 288.5 ft** **File C:\DATA\C-268\BW12.P**



Shear Modulus 4722 psi

Shear Modulus 12191 psi

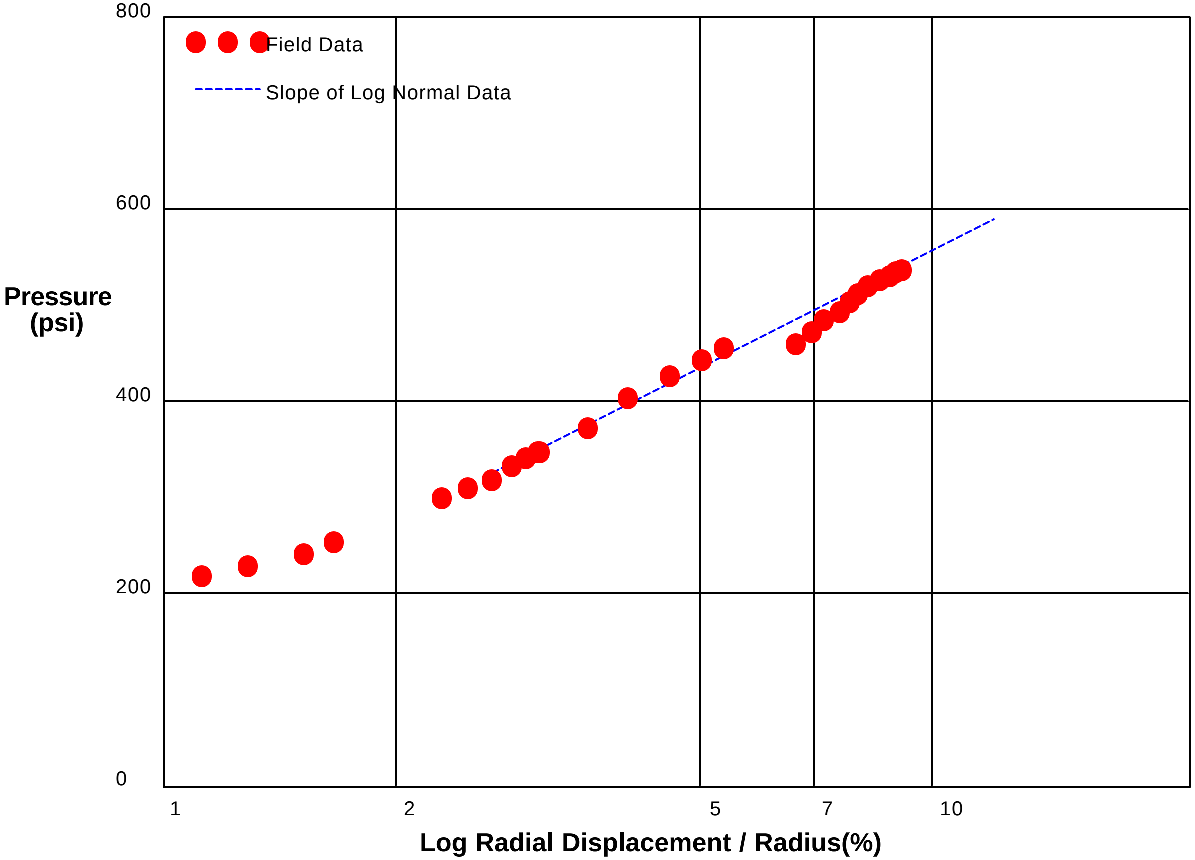
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 5, 2003**

Hole No E-223 **Depth 290 ft** C:\DATA\C-268\BW11.P



Shear Strength	**175 psi**
Limit Pressure	**804 psi**

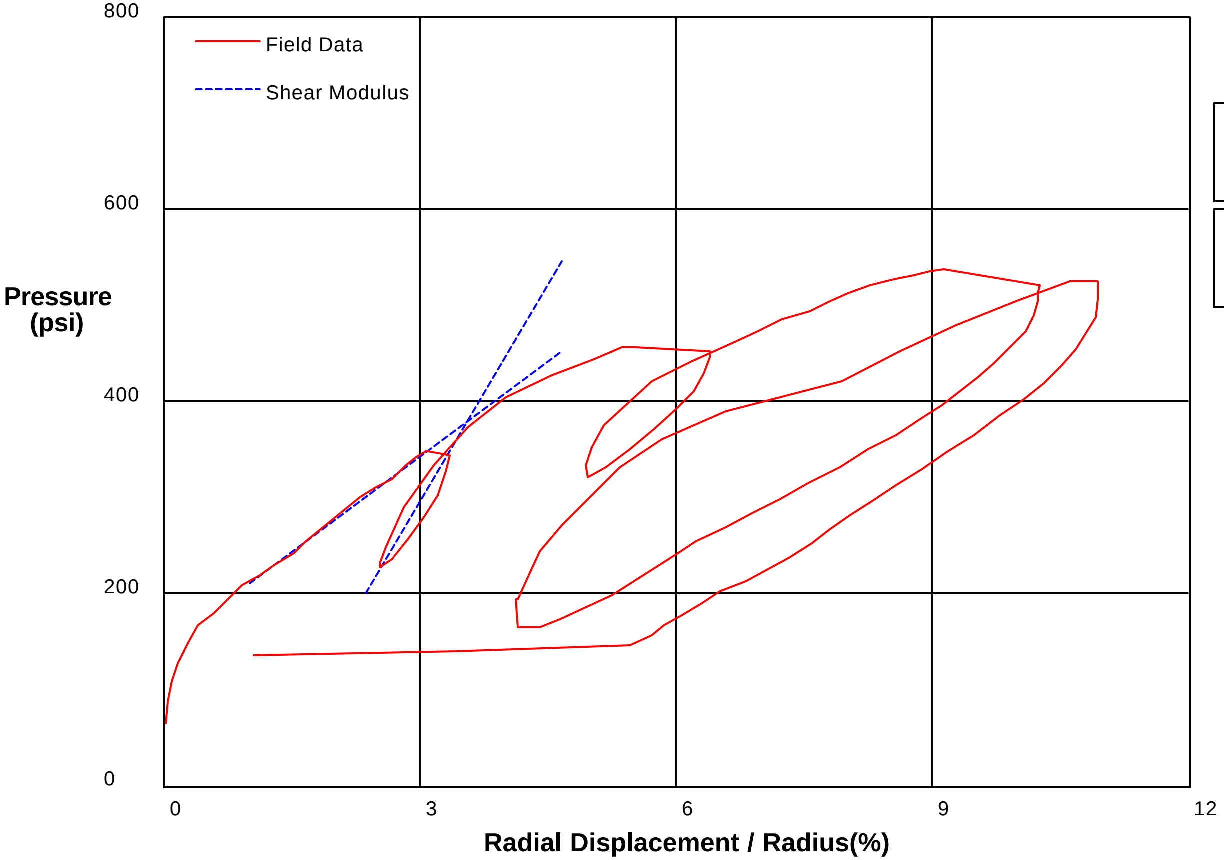
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 5, 2003**

Hole No. E-223 **Depth 290 ft** **File C:\DATA\C-268\BW11.P**



Shear Modulus 7528 psi

Shear Modulus 3304 psi

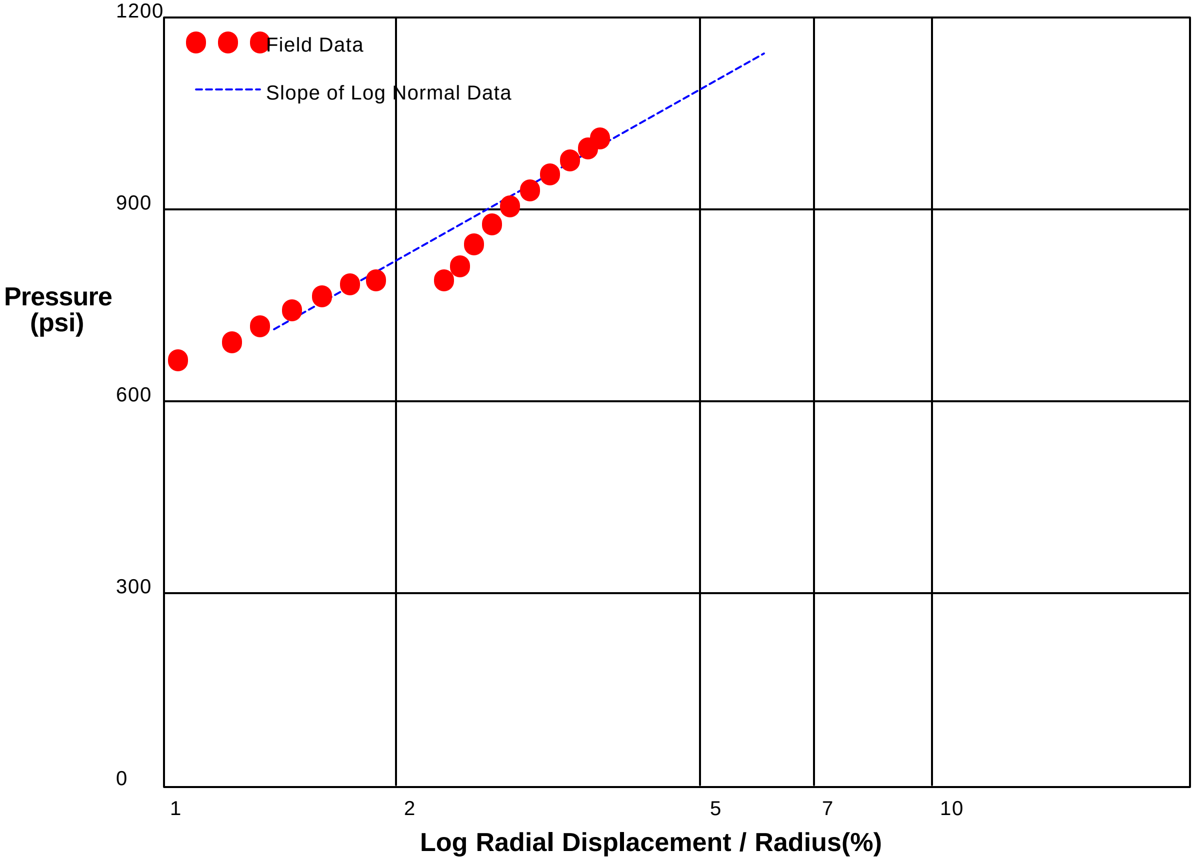
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 17 2003**

Hole No E-310 **Depth 210 ft** C:\DATA\C-268\BW18Z.P



Shear Strength	**294.5 psi**
Limit Pressure	**1709 psi**

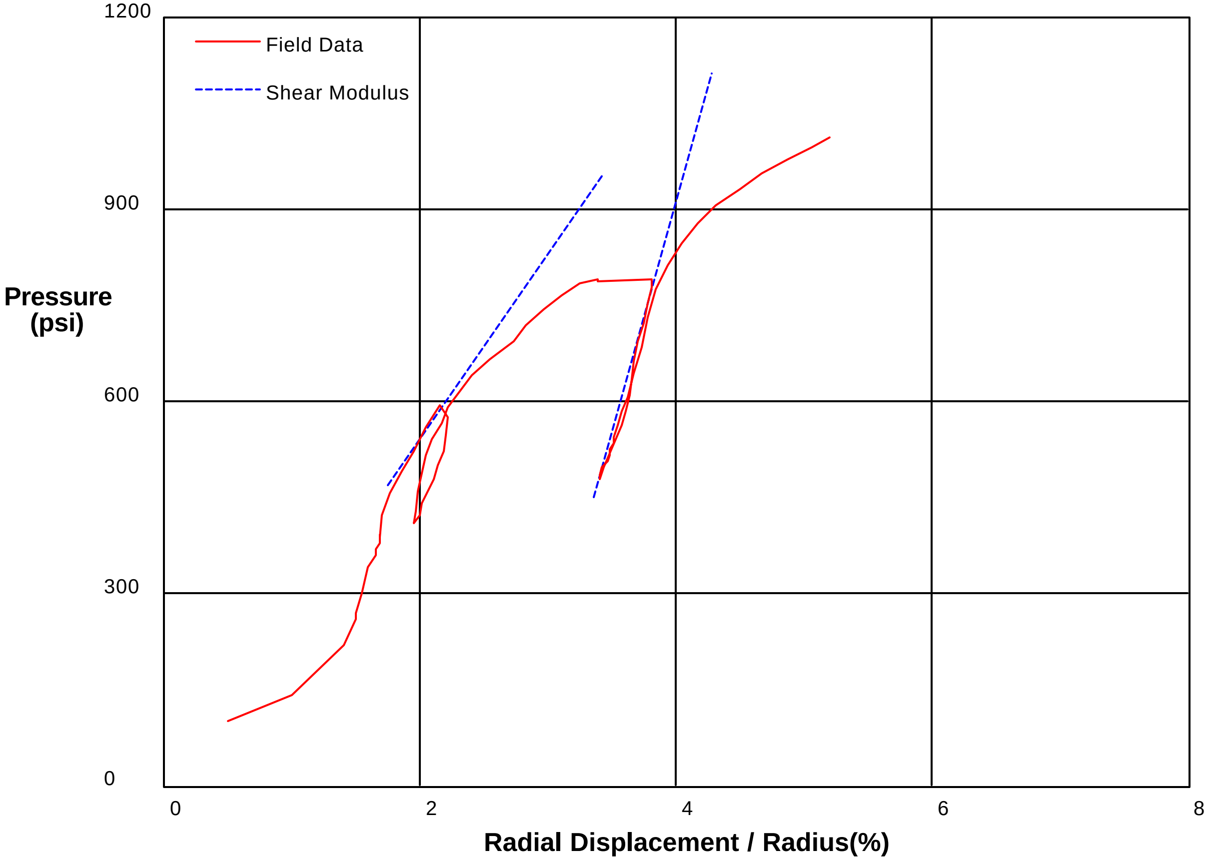
shift 1.5

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 17 2003**

Hole No. E-310 **Depth 210 ft** **File C:\DATA\C-268\BW18Z.P**



Shear Modulus 14444 psi

Shear Modulus 35842 psi

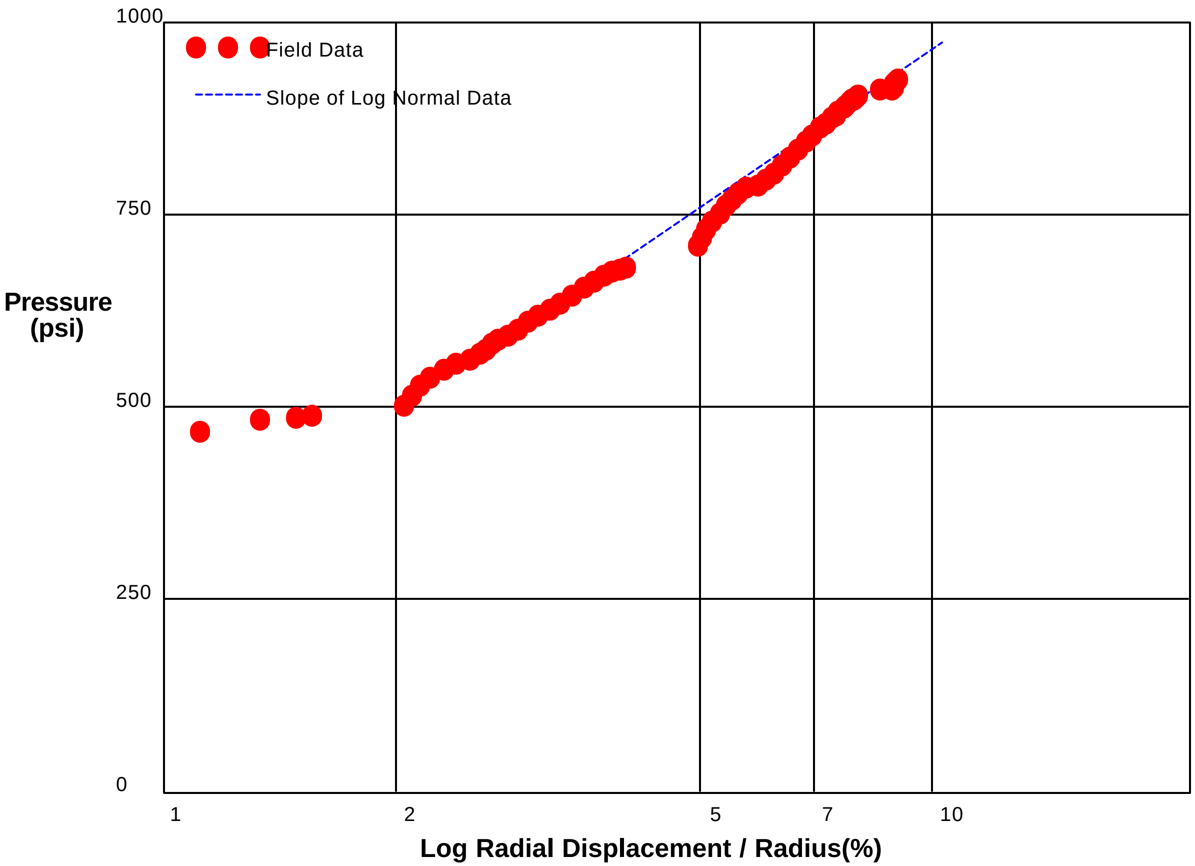
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **june24 2003**

Hole No E313 **Depth 205ft** C:\DATA\C-268\BW23COM.P



Shear Strength	**295 psi**
Limit Pressure	**1381 psi**

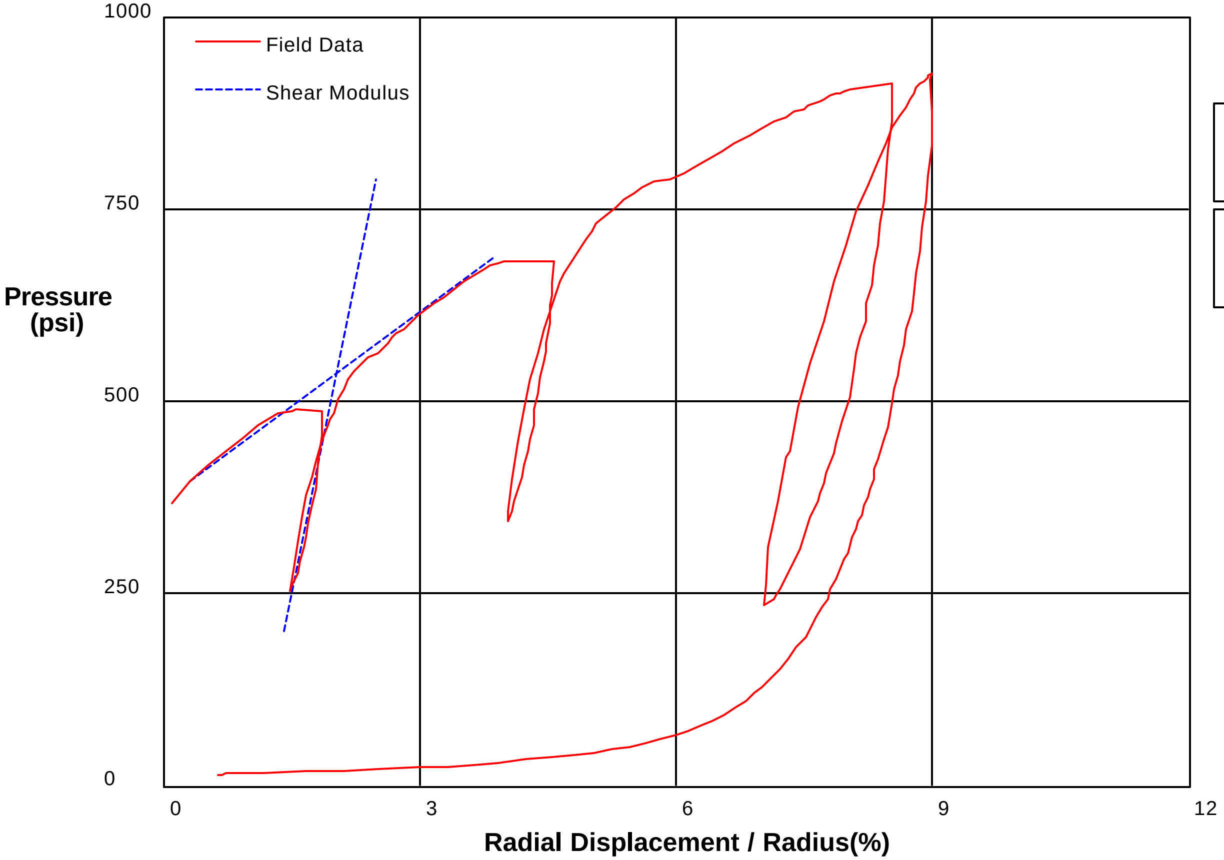
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June24, 2003**

Hole No. E-313 **Depth 205 ft** **File C:\DATA\C-268\BW23COM.P**



Shear Modulus 4136 psi

Shear Modulus 27294 psi

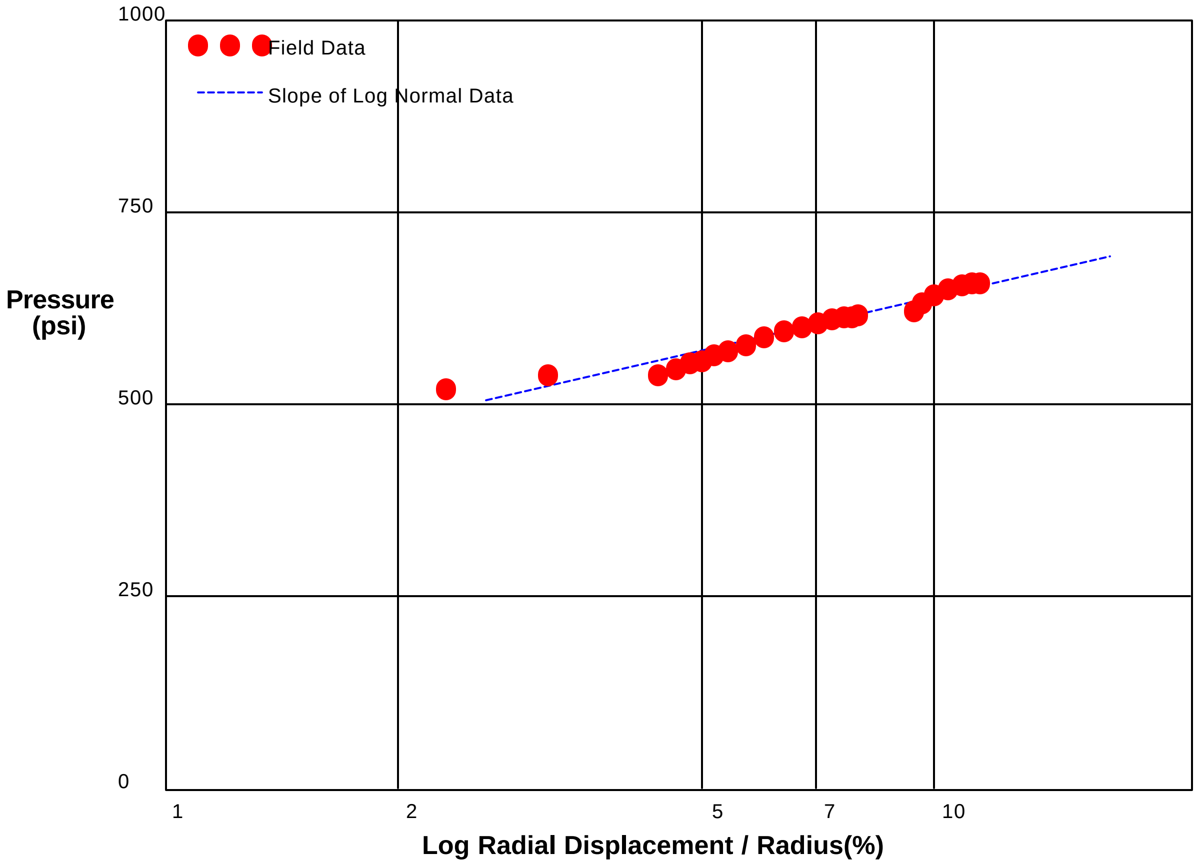
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 23, 2003**

Hole No E-334 **Depth 174 ft** C:\DATA\C-268\BW22.P



Shear Strength	**100.2 psi**
Limit Pressure	**782 psi**

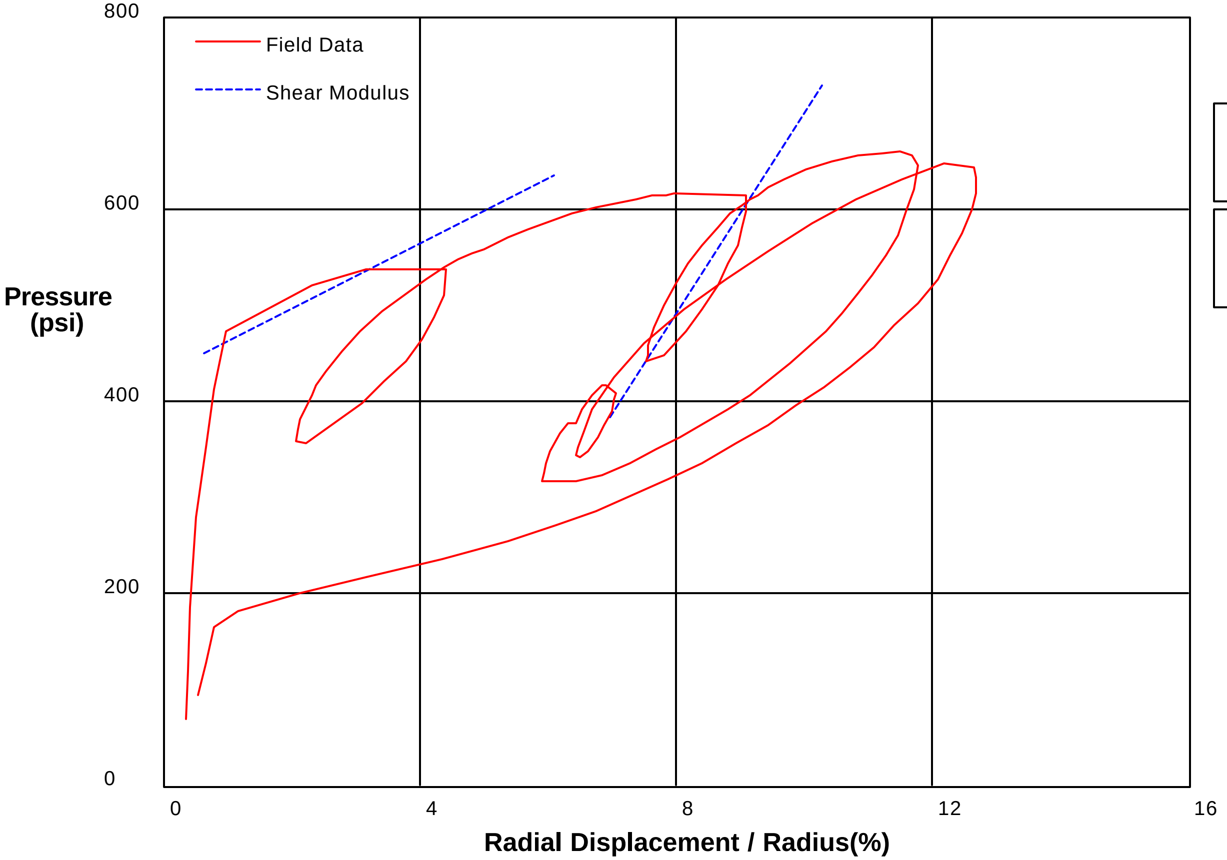
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 23, 2003**

Hole No. E-334 **Depth 174 ft** **File C:\DATA\C-268\BW22.P**



Shear Modulus 1704 psi

Shear Modulus 5220 psi

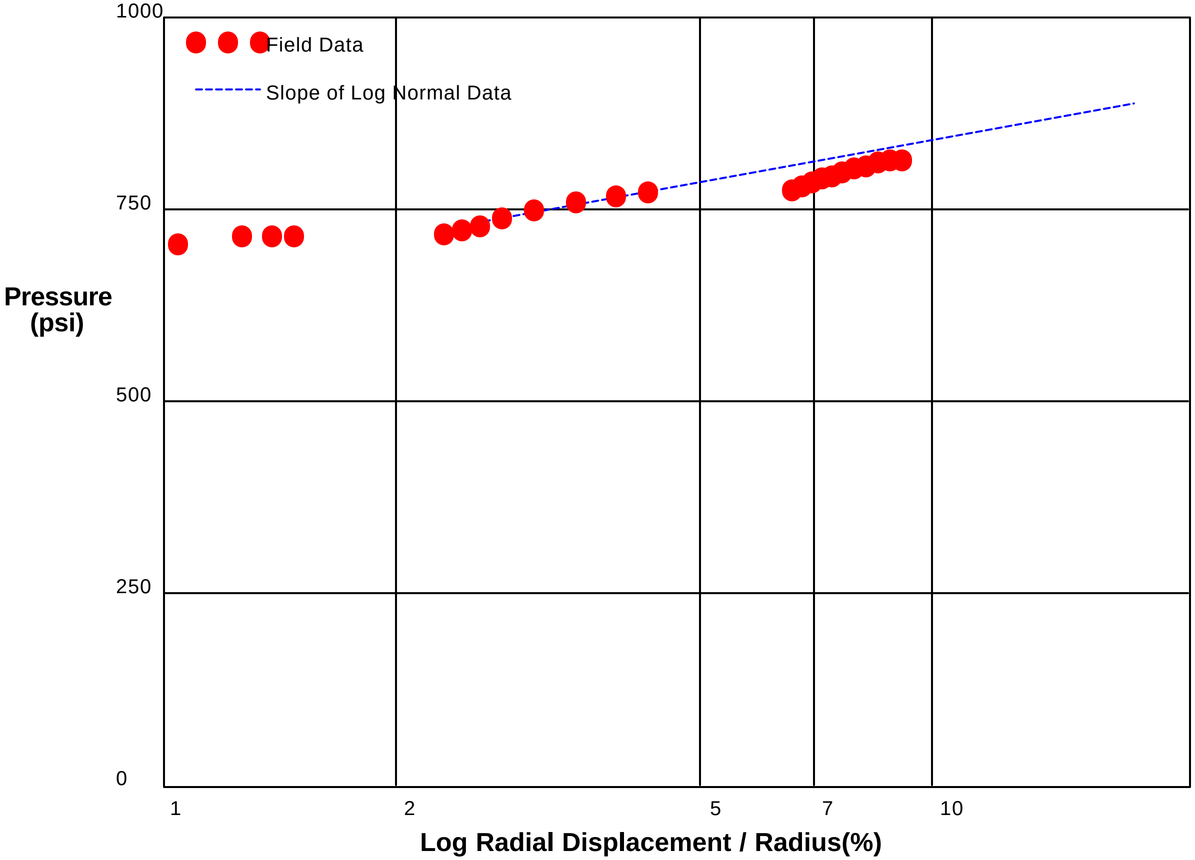
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 23, 2003**

Hole No E-334 **Depth 174 ft** C:\DATA\C-268\BW21.P



Shear Strength	**78.3 psi**
Limit Pressure	**951 psi**

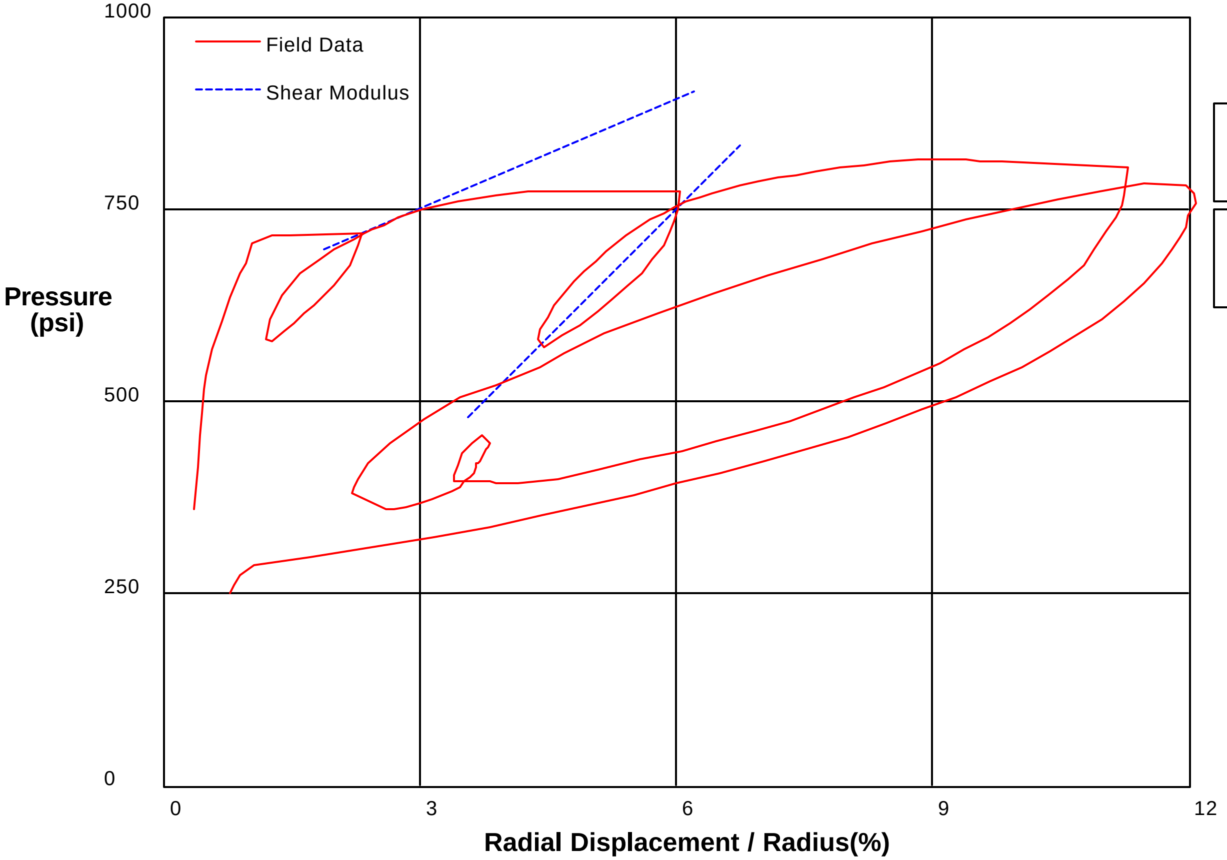
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **June 23, 2003**

Hole No. E-334 **Depth 174 ft** **File C:\DATA\C-268\BW21.P**



Shear Modulus 2386 psi

Shear Modulus 5555 psi

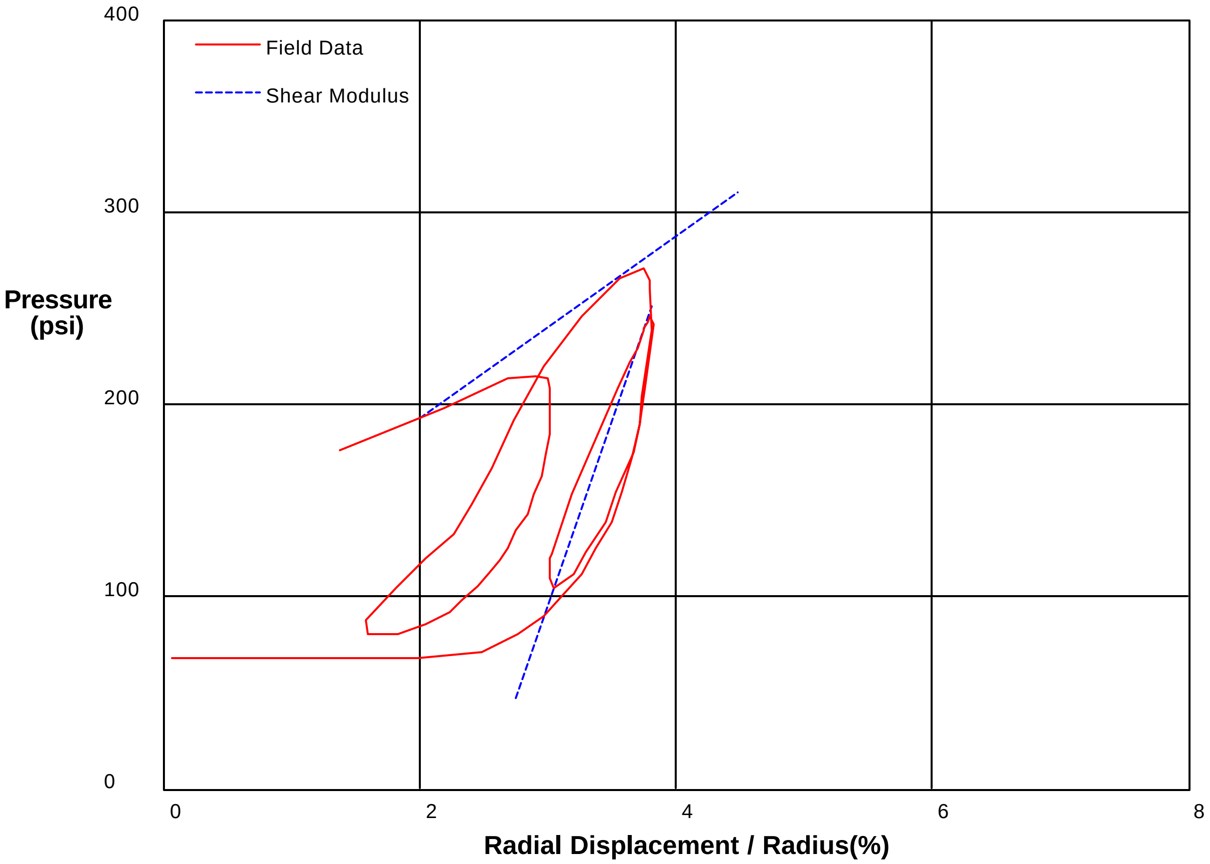
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **May 12, 2003**

Hole No. E-339 **Depth 186.1 ft** **File C:\DATA\C-268\BW1.P**



Shear Modulus 9607 psi

Shear Modulus 2357 psi

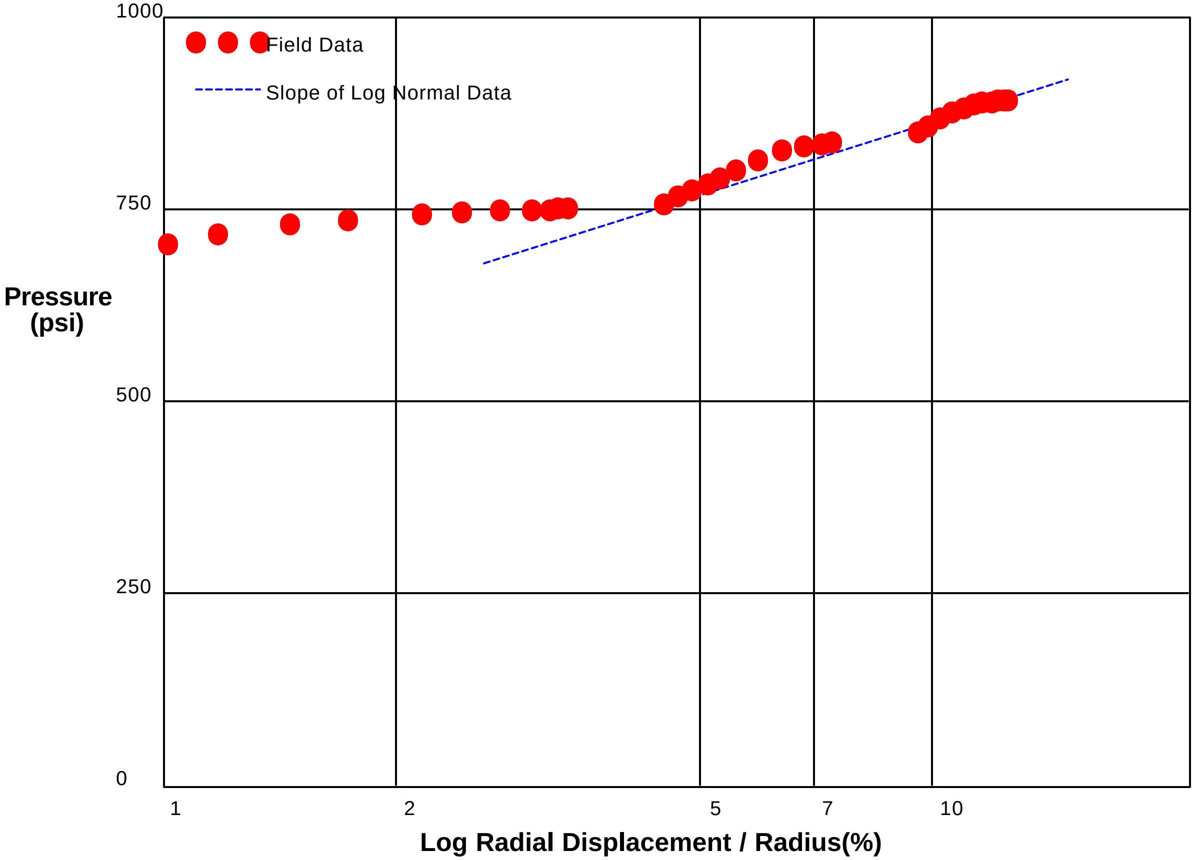
shift 8

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **May 14, 2003**

Hole No E-339 **Depth 264.7 ft** C:\DATA\C-268\BW4.P



Shear Strength	**136.8 psi**
Limit Pressure	**1057 psi**

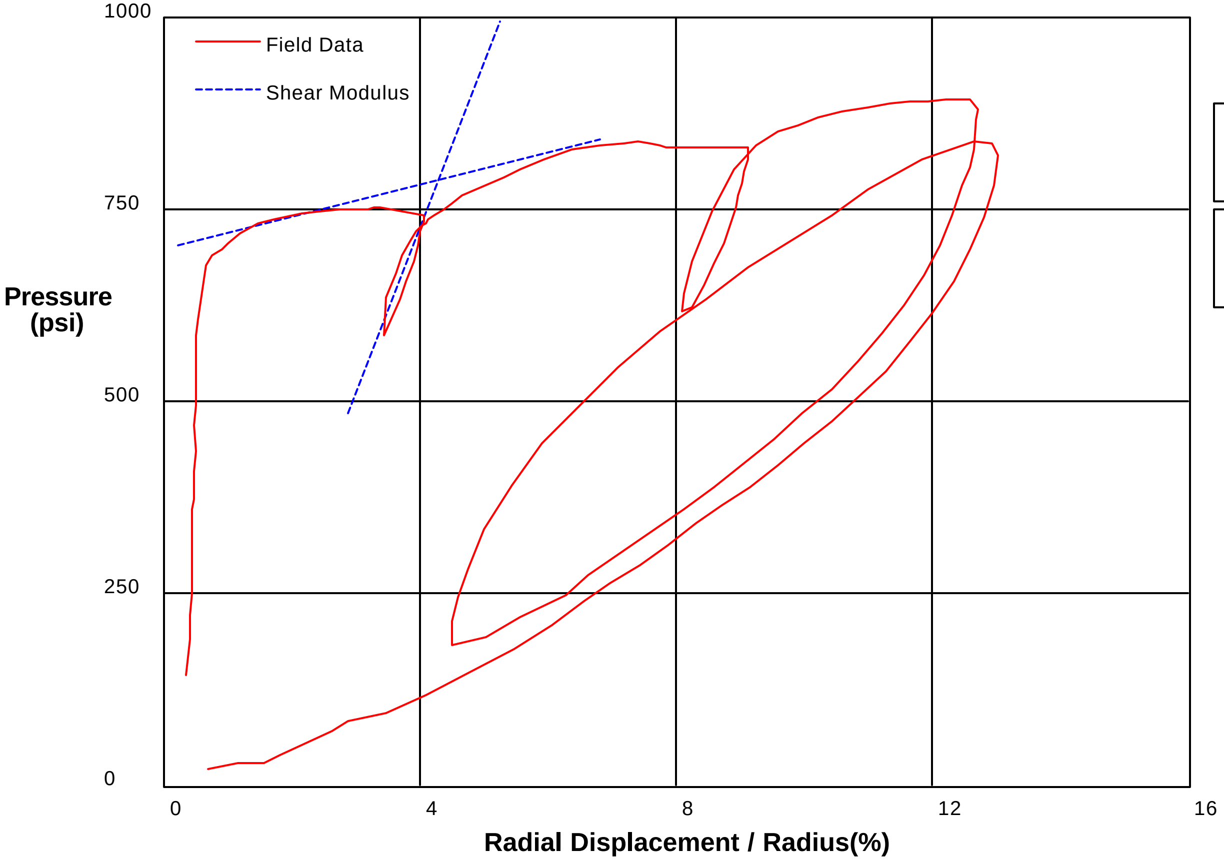
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **May 14, 2003**

Hole No. E-339 **Depth 264.7 ft** **File C:\DATA\C-268\BW4.P**



Shear Modulus 1038 psi

Shear Modulus 10745 psi

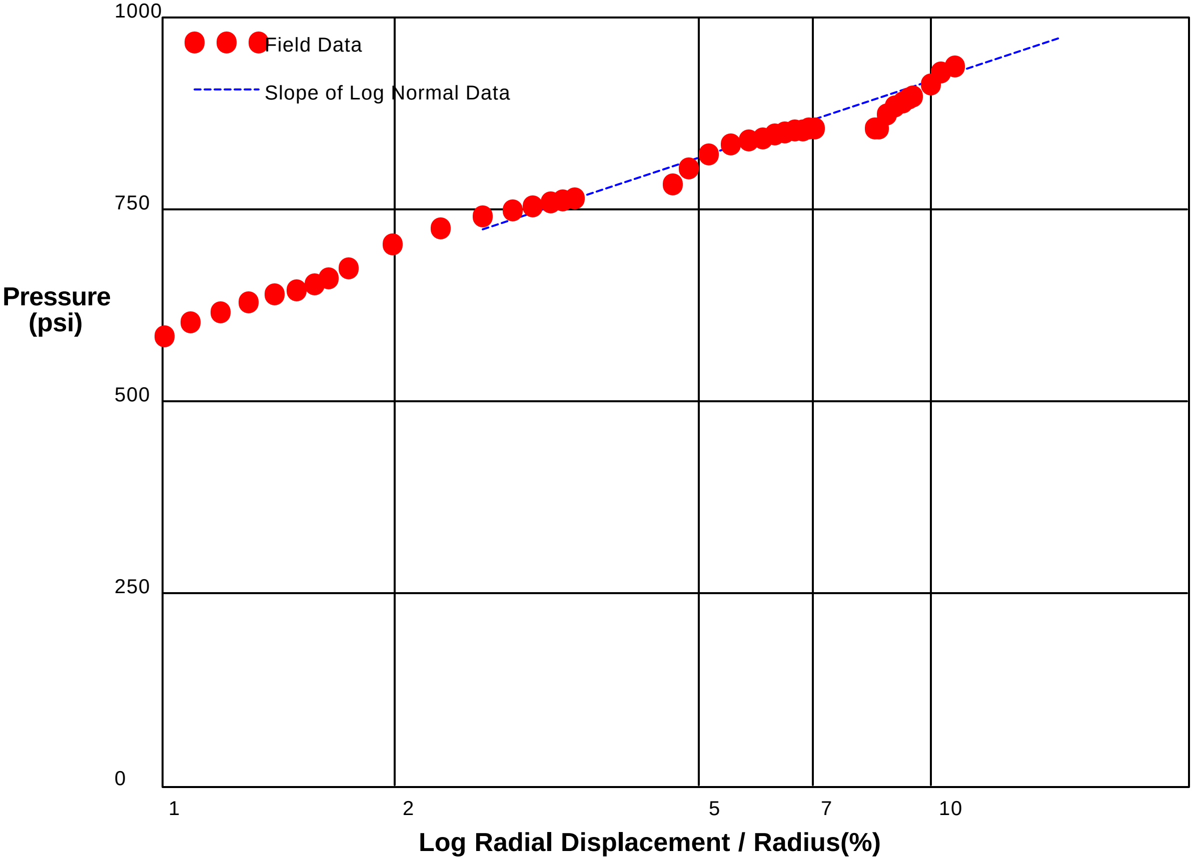
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **May 14, 2003**

Hole No E-339 **Depth 266.2 ft** C:\DATA\C-268\BW3COM.P



Shear Strength	**143.4 psi**
Limit Pressure	**1120 psi**

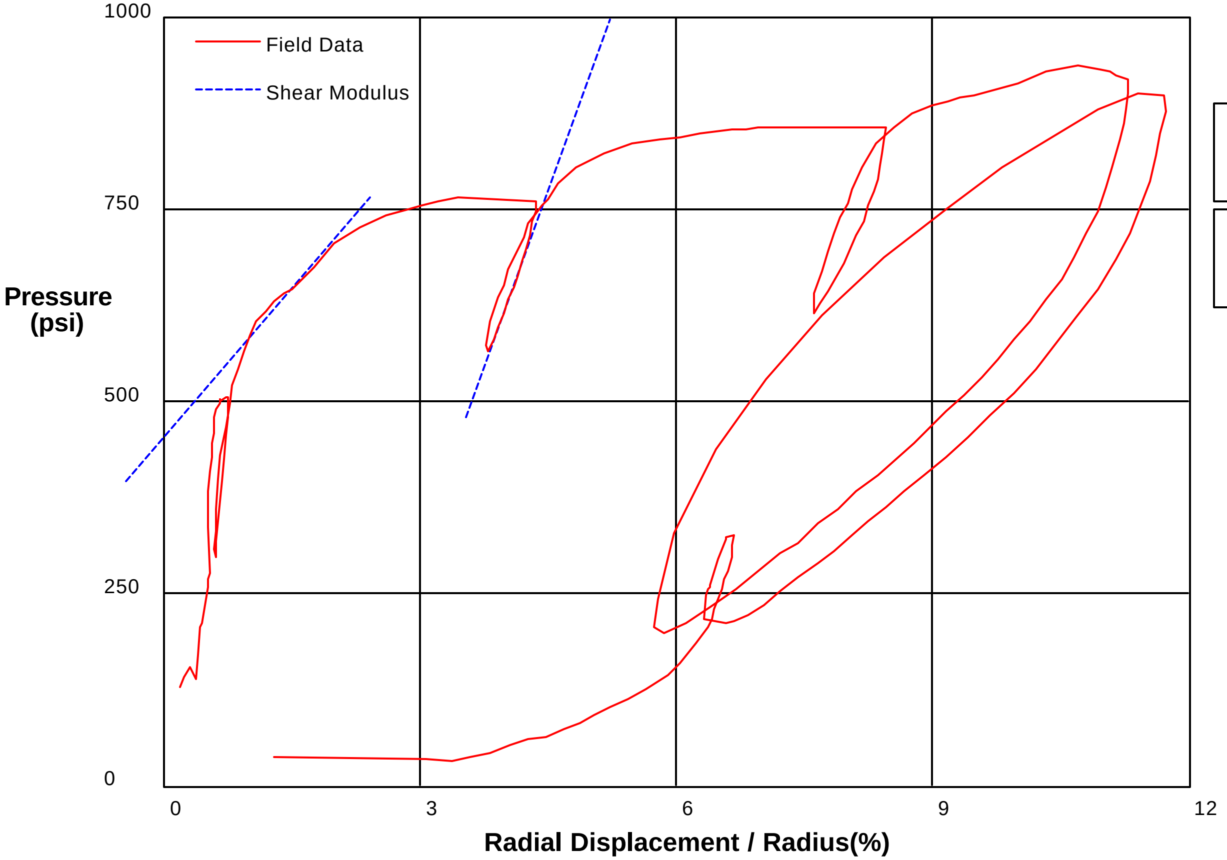
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **May 14, 2003**

Hole No. E-339 **Depth 266.2 ft** **File C:\DATA\C-268\BW3COM.P**



Shear Modulus 6532 psi

Shear Modulus 15239 psi

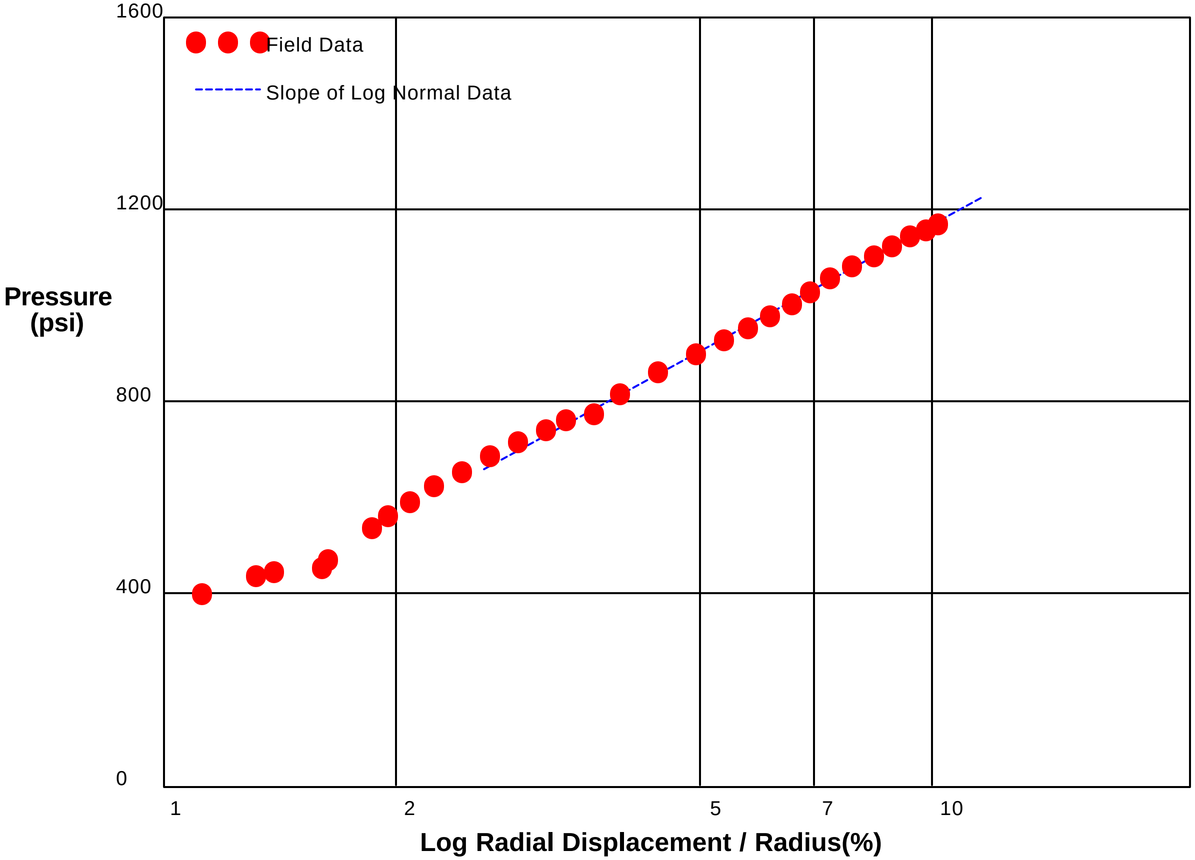
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 29, 2003**

Hole No E-403 **Depth 239.5 ft** C:\DATA\C-268\BW38.P



Shear Strength **378.1 psi**
Limit Pressure **1702 psi**

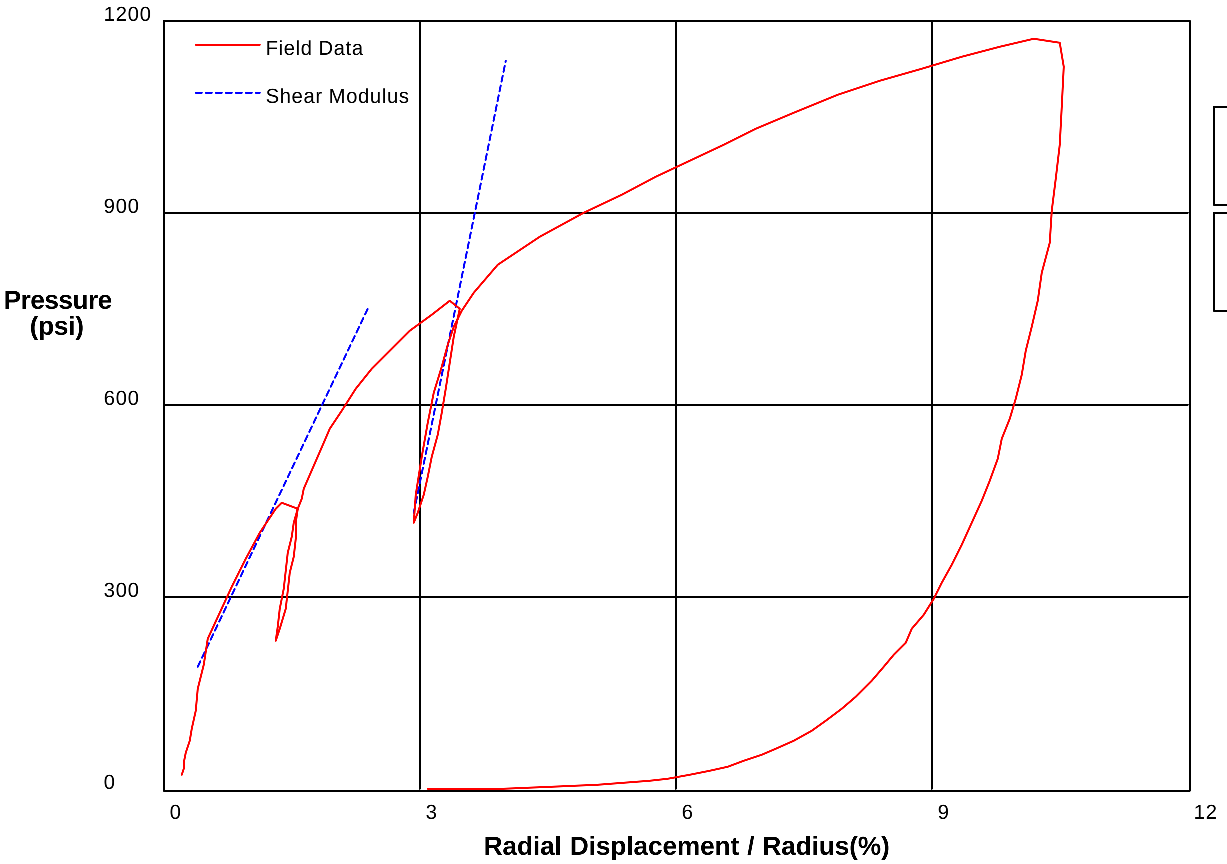
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 29, 2003**

Hole No. E-403 **Depth 239.5 ft** **File C:\DATA\C-268\BW38.P**



Shear Modulus 14120 psi

Shear Modulus 32753 psi

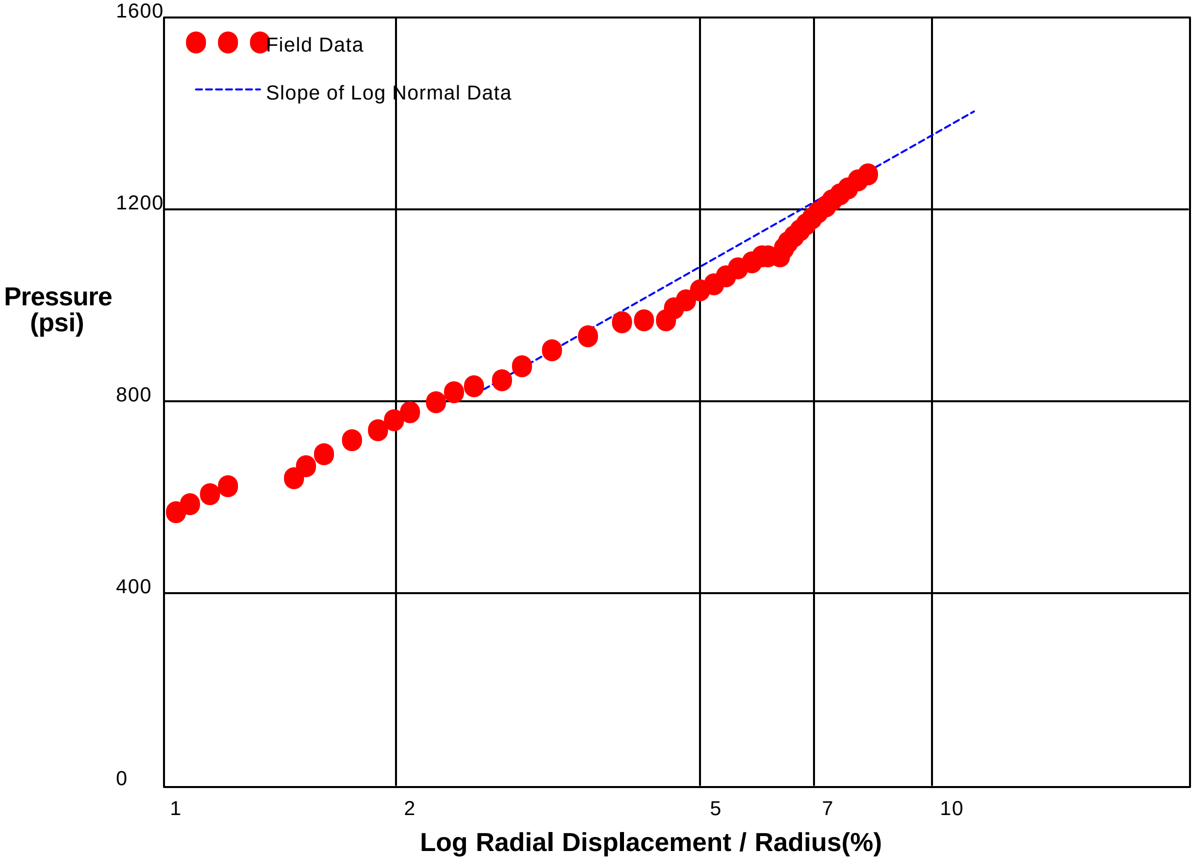
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 29, 2003**

Hole No E-403 **Depth 241 ft** C:\DATA\C-268\BW37.P



Shear Strength	**392.7 psi**
Limit Pressure	**1909 psi**

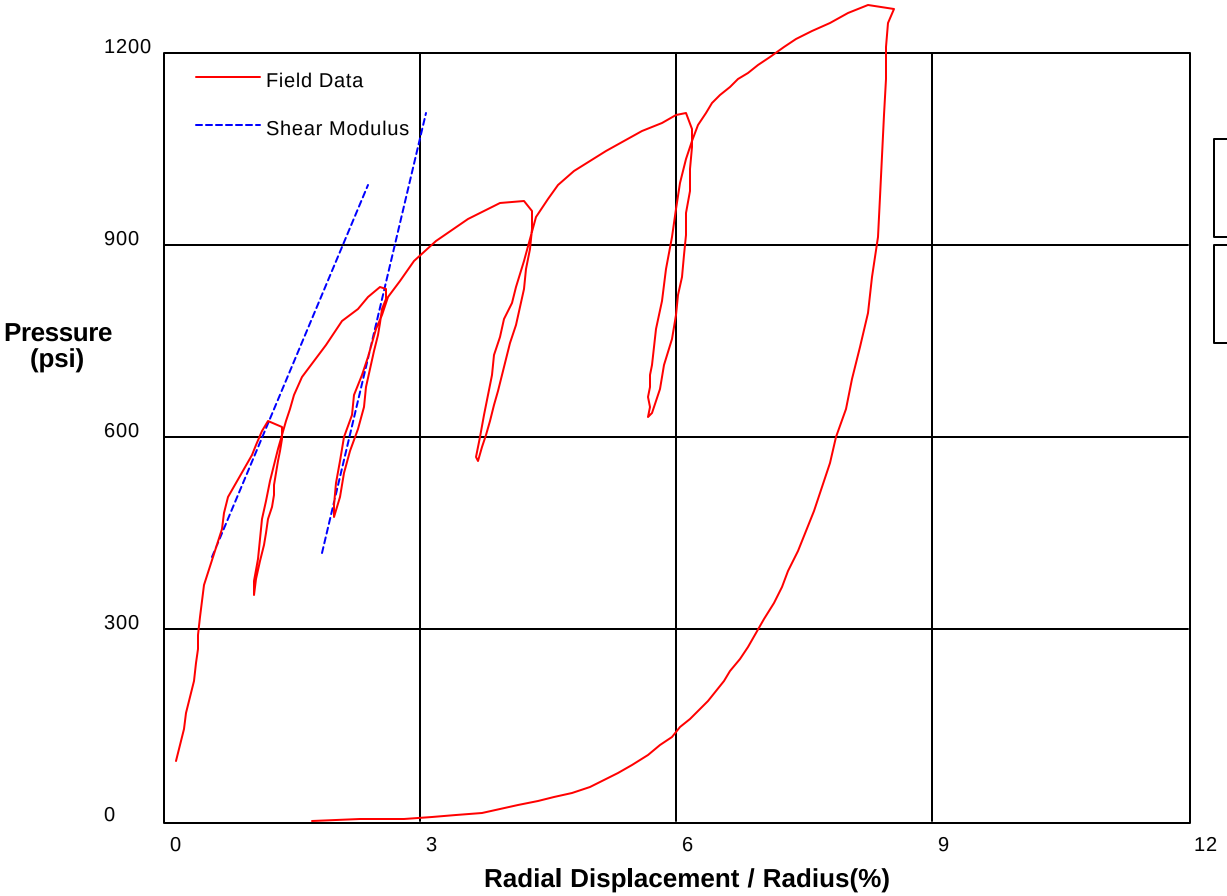
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 29, 2003**

Hole No. E-403 **Depth 241 ft** **File C:\DATA\C-268\BW37.P**



Shear Modulus 15897 psi

Shear Modulus 27763 psi

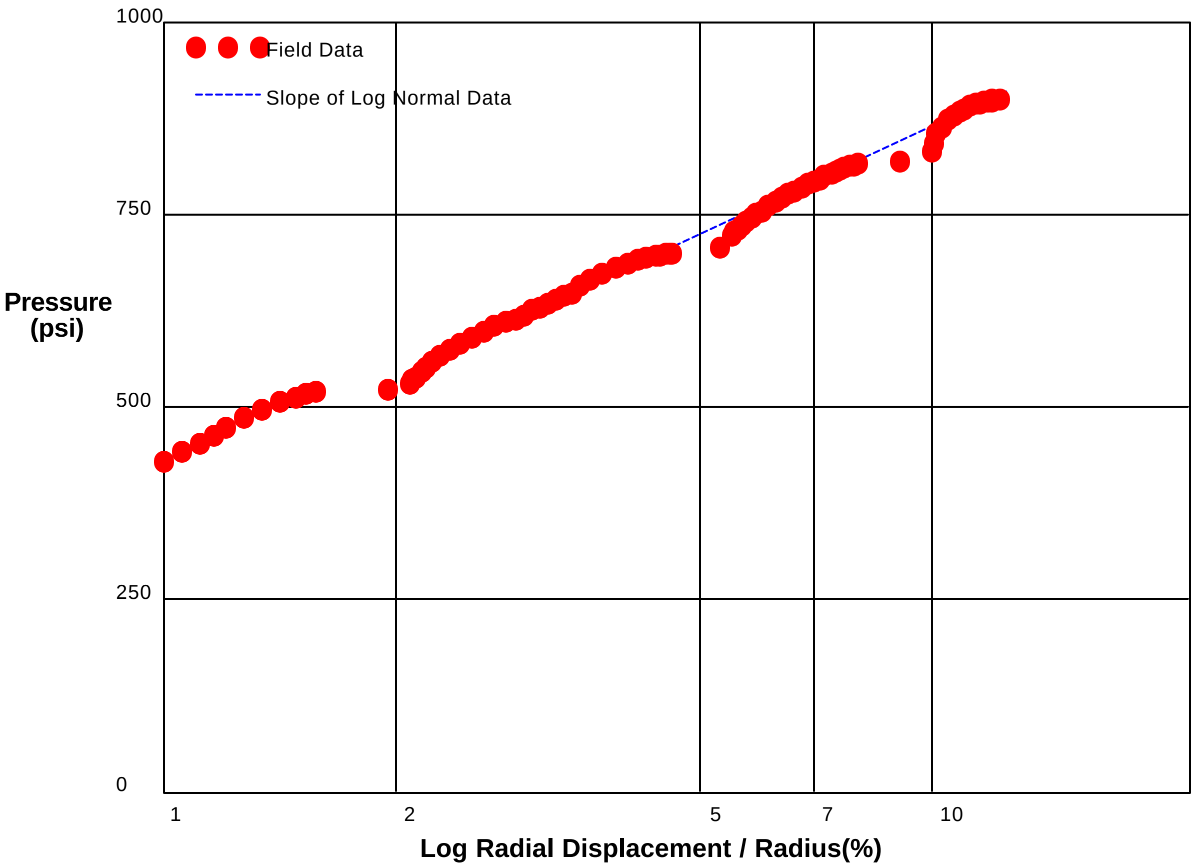
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 16, 2003**

Hole No E-406 **Depth 345 ft** C:\DATA\C-268\BW24X.P



Shear Strength	**202.2 psi**
Limit Pressure	**1150 psi**

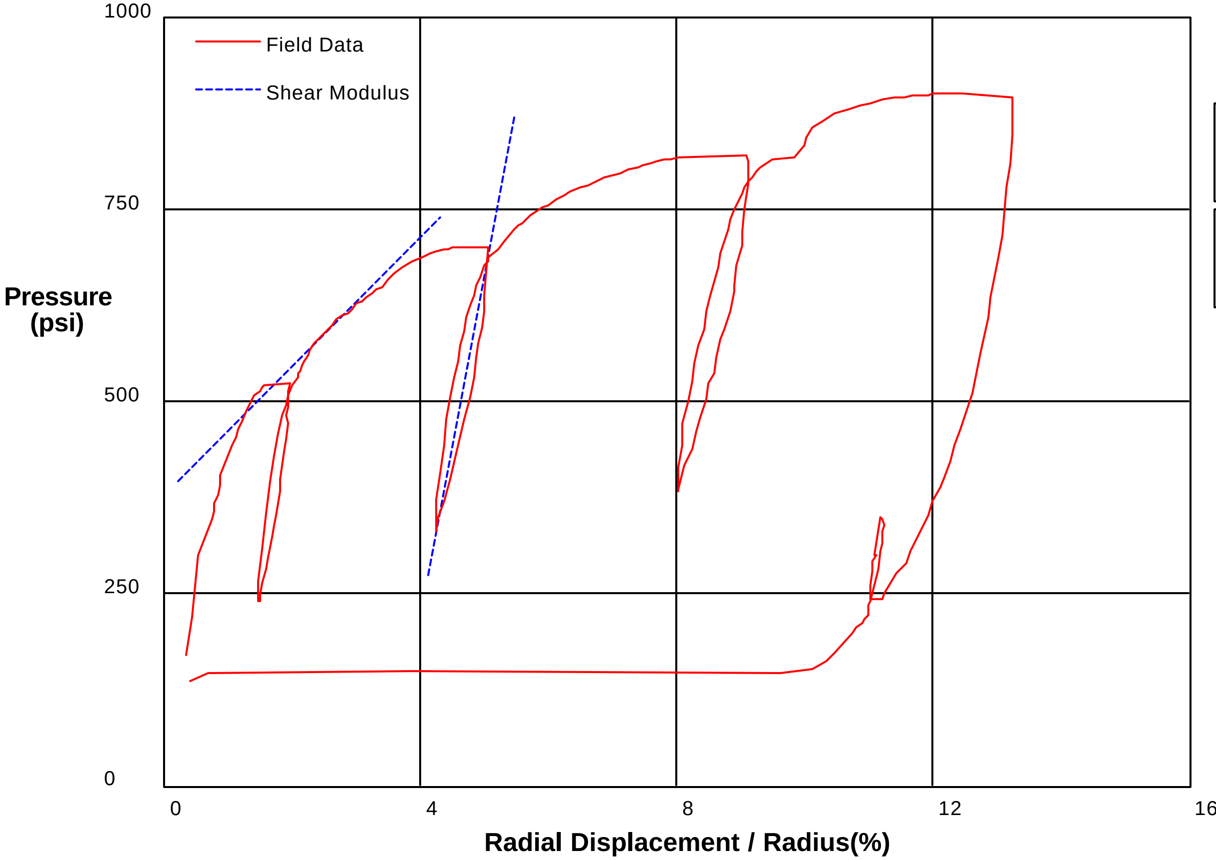
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 16, 2003**

Hole No. E-406 **Depth 345 ft** **File C:\DATA\C-268\BW24X.P**



Shear Modulus 4208 psi

Shear Modulus 22395 psi

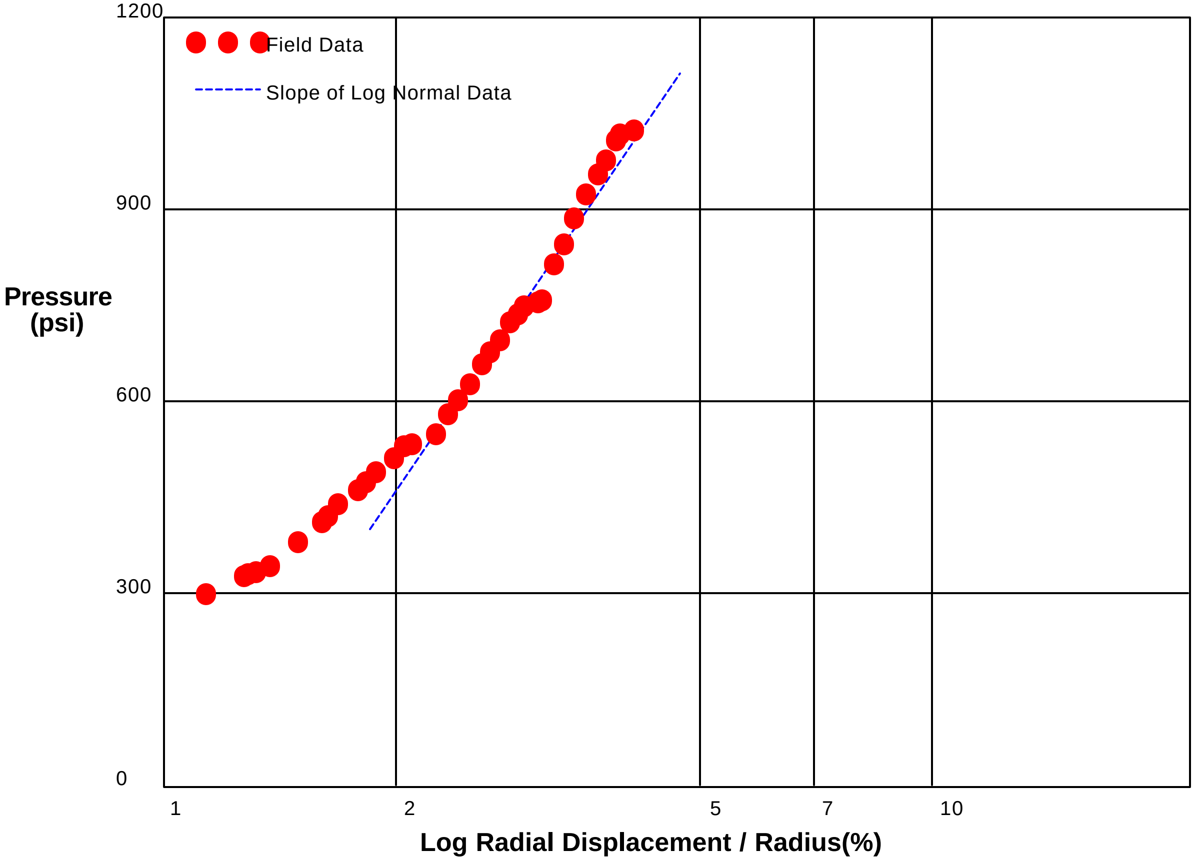
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 17, 2003**

Hole No E-406 **Depth 413.5 ft** C:\DATA\C-268\BW27Z.P



Shear Strength	**767.1 psi**
Limit Pressure	**2776 psi**

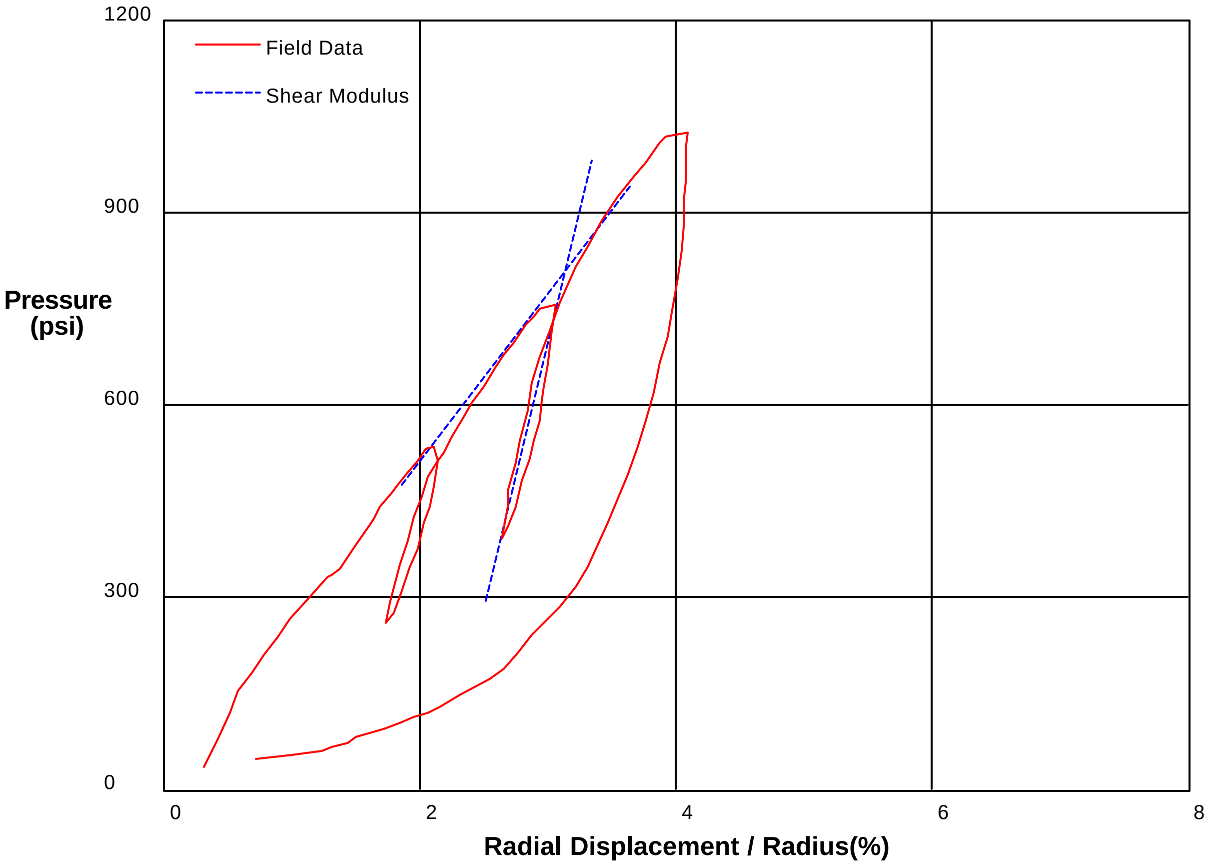
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 17, 2003**

Hole No. E-406 **Depth 413.5 ft** **File C:\DATA\C-268\BW27Z.P**



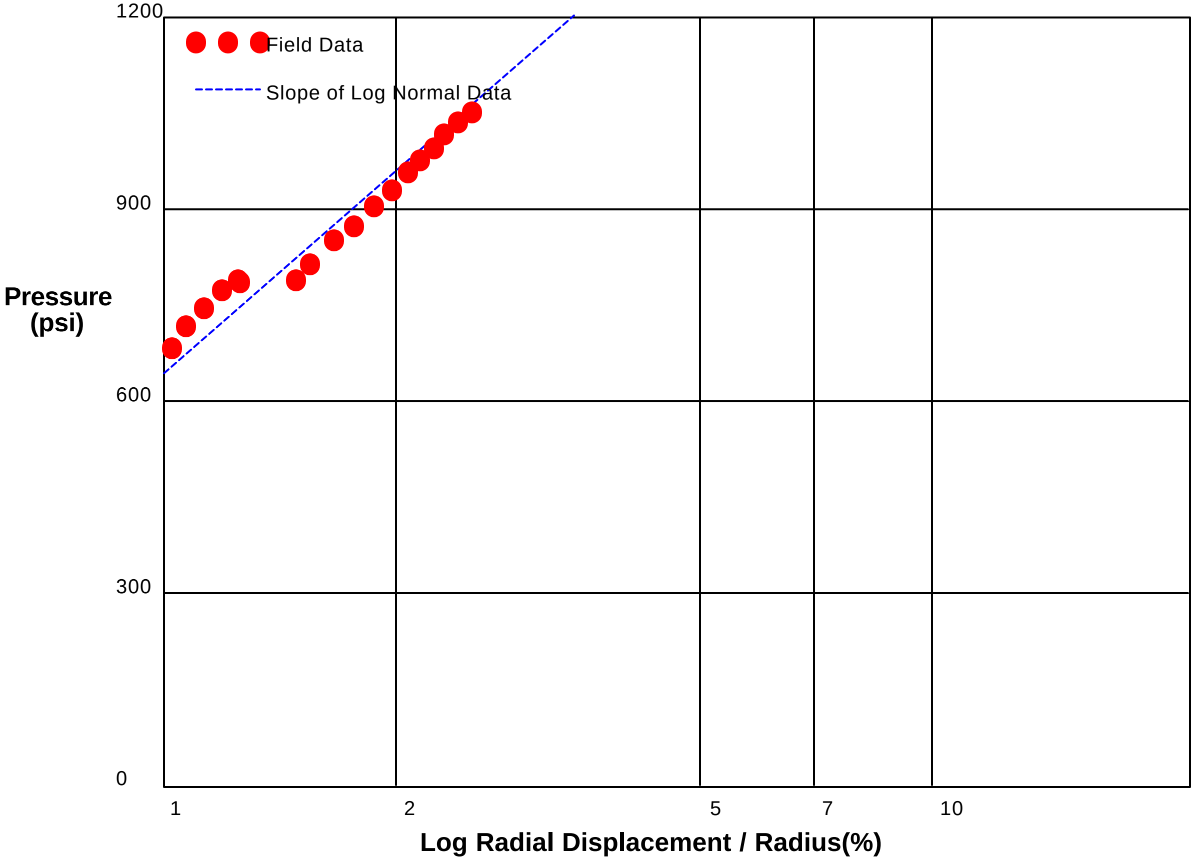
Shear Modulus 13023 psi

Shear Modulus 41645 psi

shift 0

HUGHES

PRESSUREMETER DATA		**Camp Dresser & McKee Inc.**
King County Brightwater Project		**July 17, 2003**
Hole No E-406	**Depth 415 ft**	C:\DATA\C-268\BW26Z.P



Shear Strength	**453.4 psi**
Limit Pressure	**2329 psi**

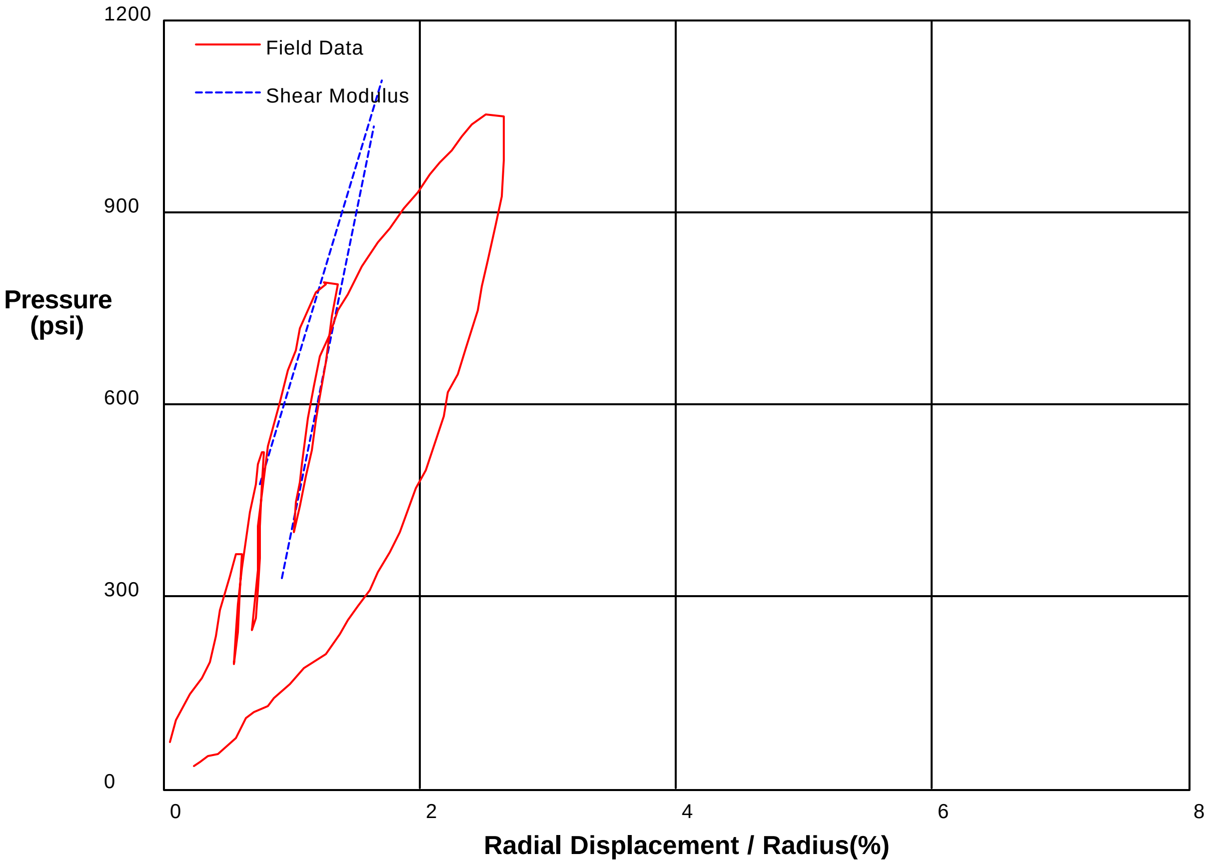
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 17, 2003**

Hole No. E-406 **Depth 415 ft** **File C:\DATA\C-268\BW26Z.P**



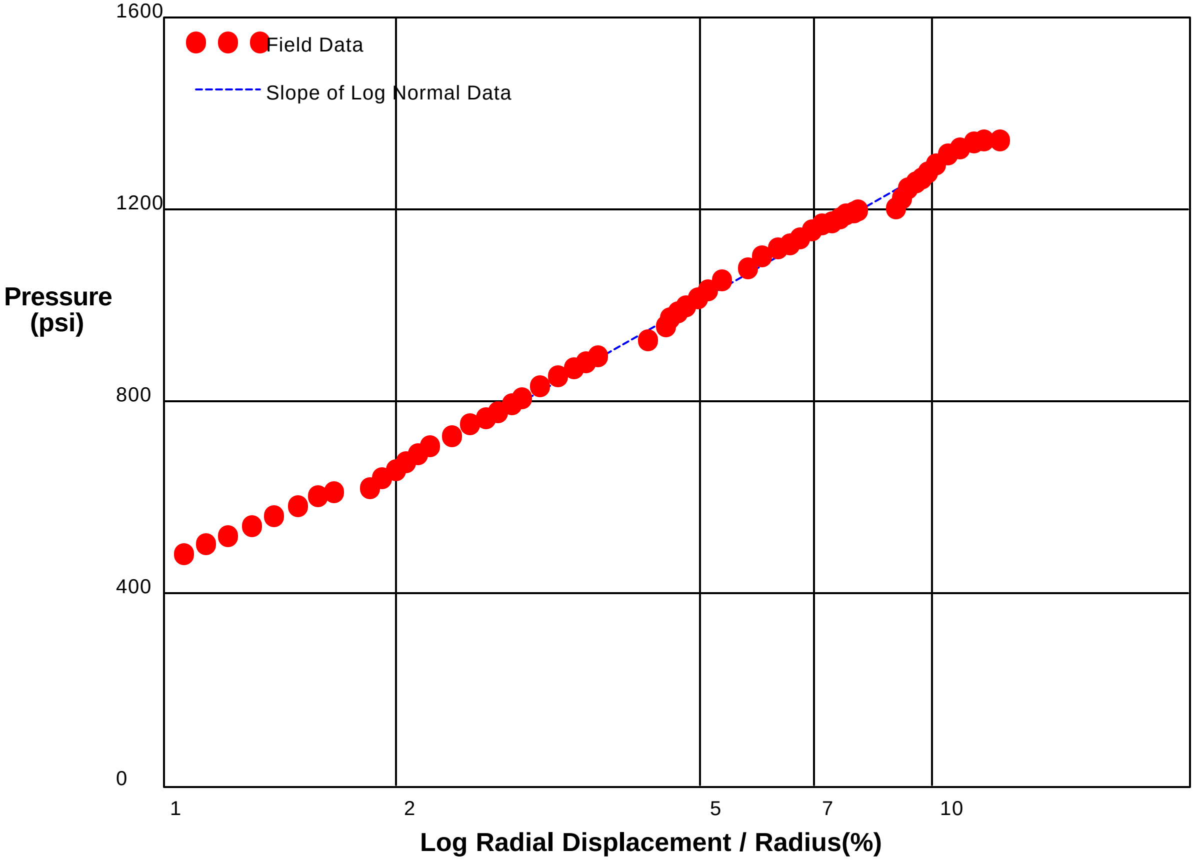
Shear Modulus 33043 psi

Shear Modulus 49130 psi

shift 0

HUGHES

PRESSUREMETER DATA	**Camp Dresser & McKee Inc.**	
King County Brightwater Project		**July 30, 2003**
Hole No E-408	**Depth 419.5 ft**	C:\DATA\C-268\BW42.P



Shear Strength	**392.7 psi**
Limit Pressure	**1837 psi**

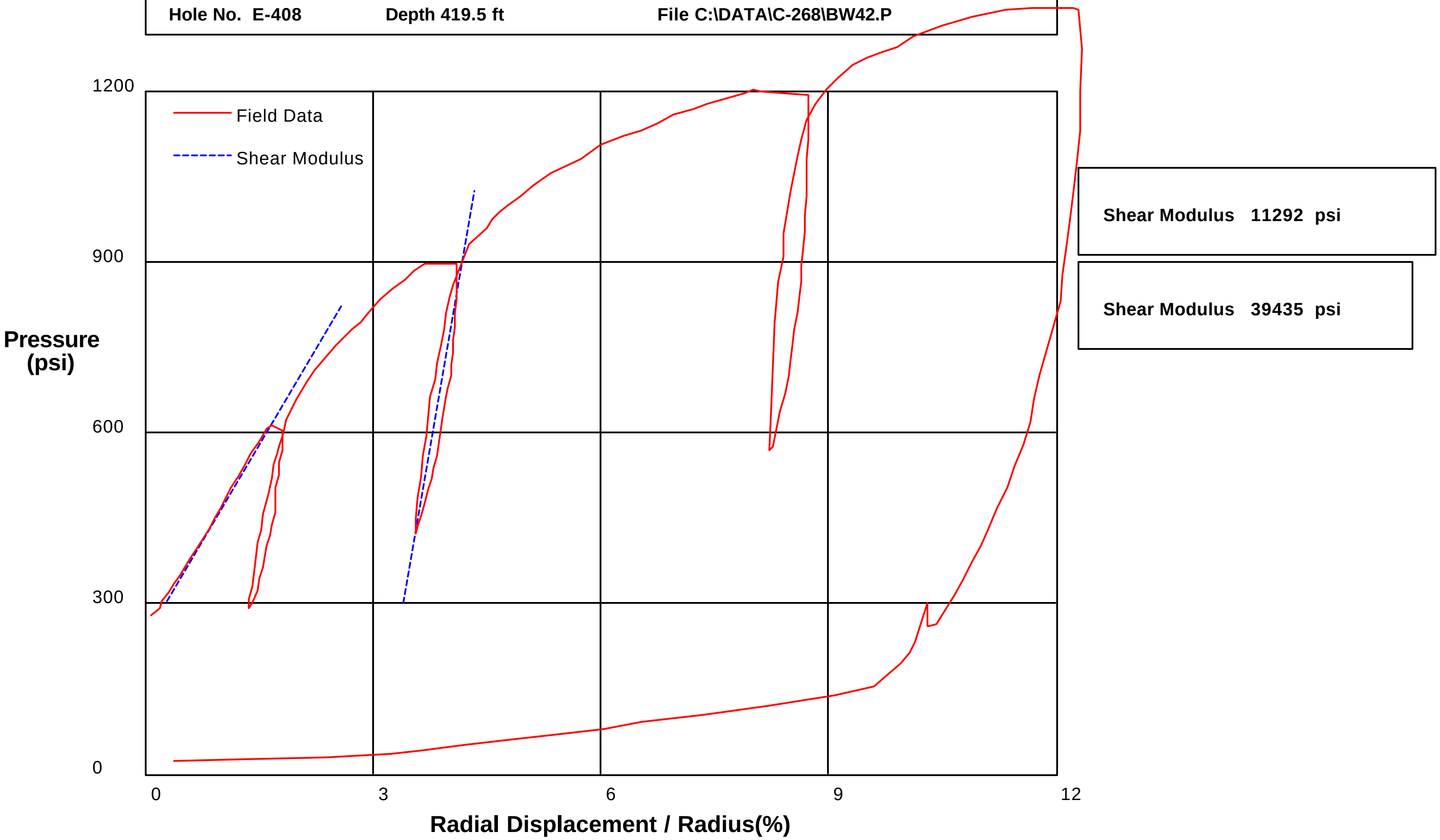
shift 1

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 30, 2003**

Hole No. E-408 **Depth 419.5 ft** **File C:\DATA\C-268\BW42.P**



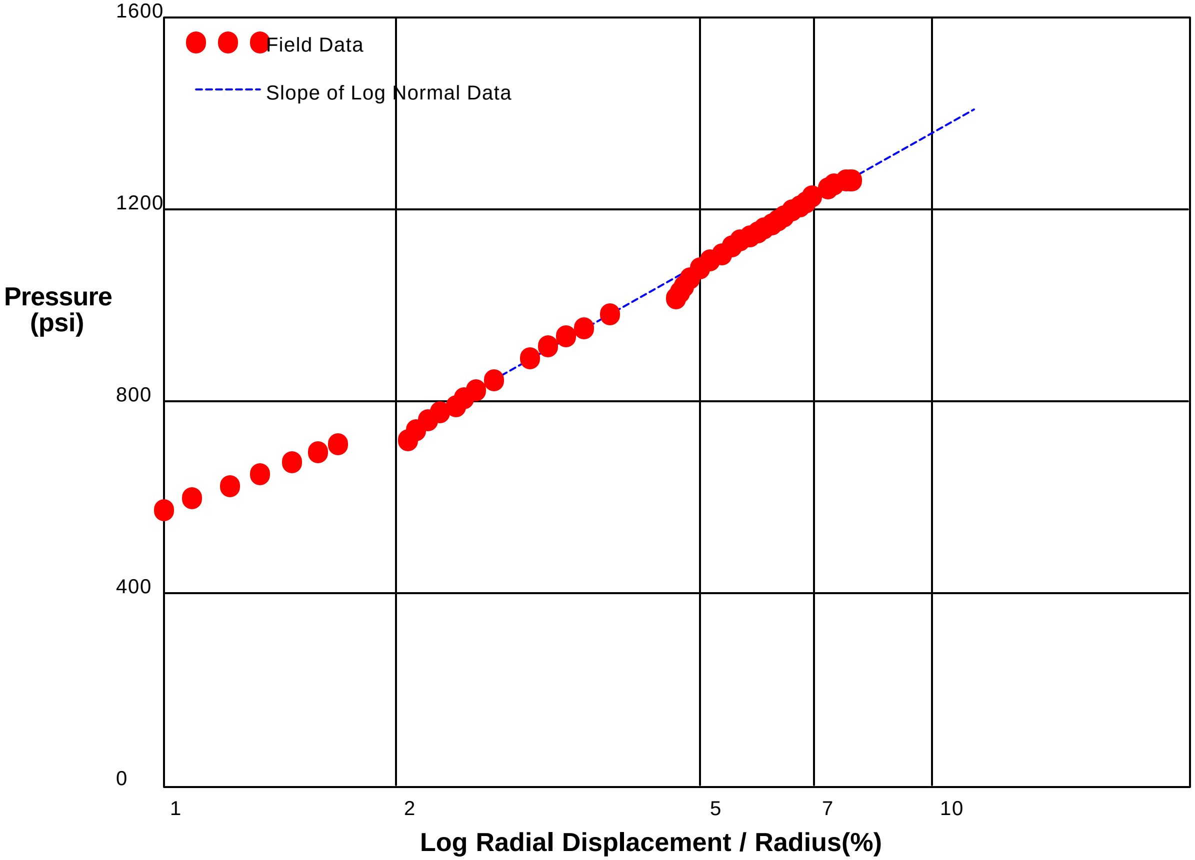
shift 1

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 30, 2003**

Hole No E-408 **Depth 421 ft** C:\DATA\C-268\BW41COM.P



Shear Strength	**392.7 psi**
Limit Pressure	**1915 psi**

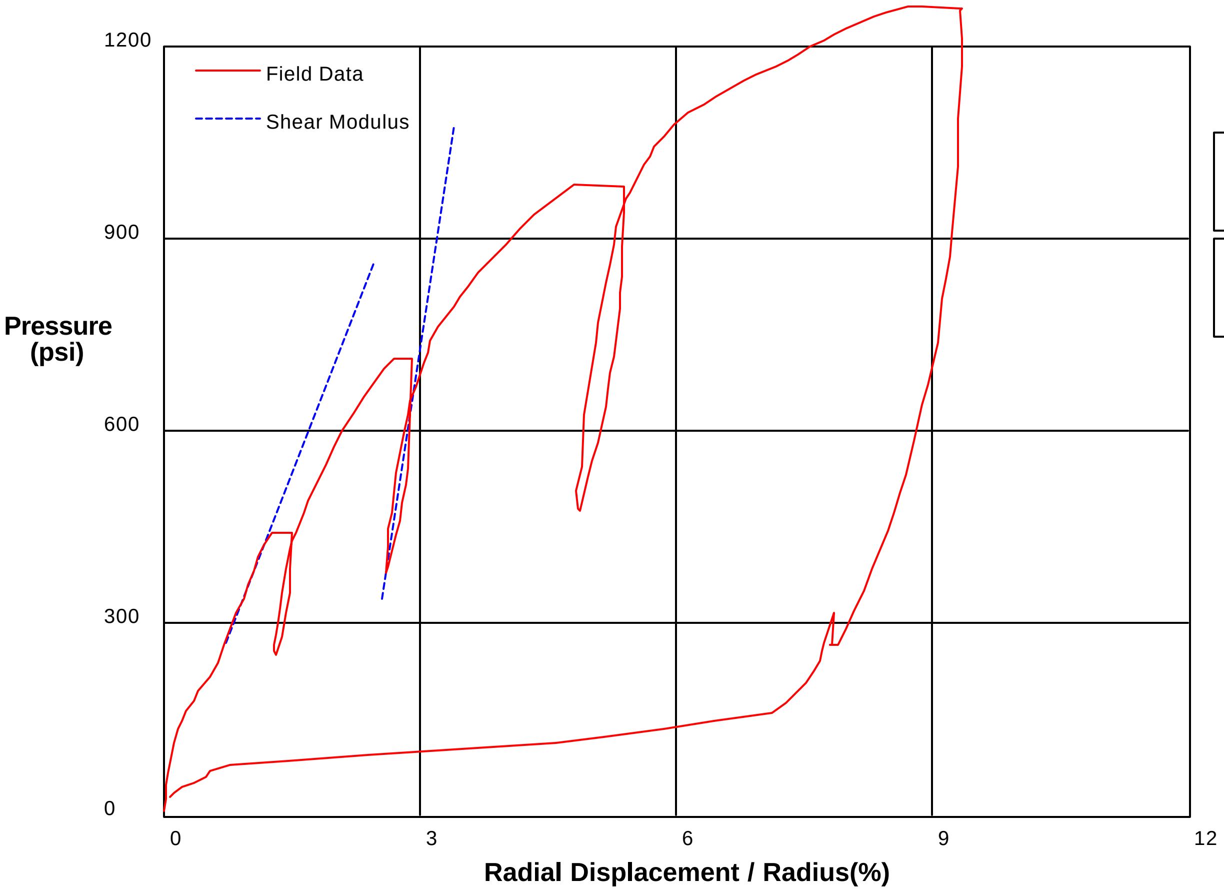
shift 1

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 30, 2003**

Hole No. E-408 **Depth 421 ft** **File C:\DATA\C-268\BW41COM.P**



Shear Modulus 16904 psi

Shear Modulus 43703 psi

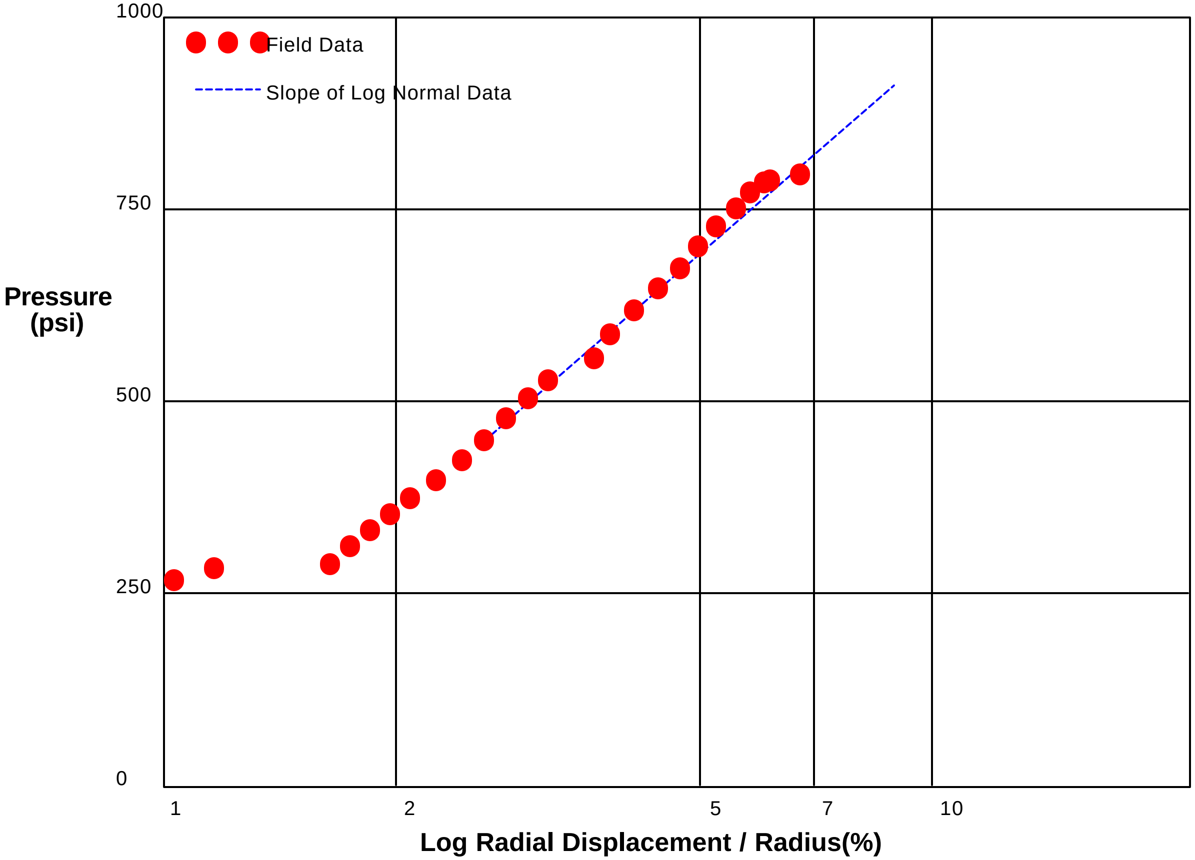
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 23, 2003**

Hole No E-412 **Depth 173.5 ft** C:\DATA\C-268\BW34.P



Shear Strength	**377.8 psi**
Limit Pressure	**1488 psi**

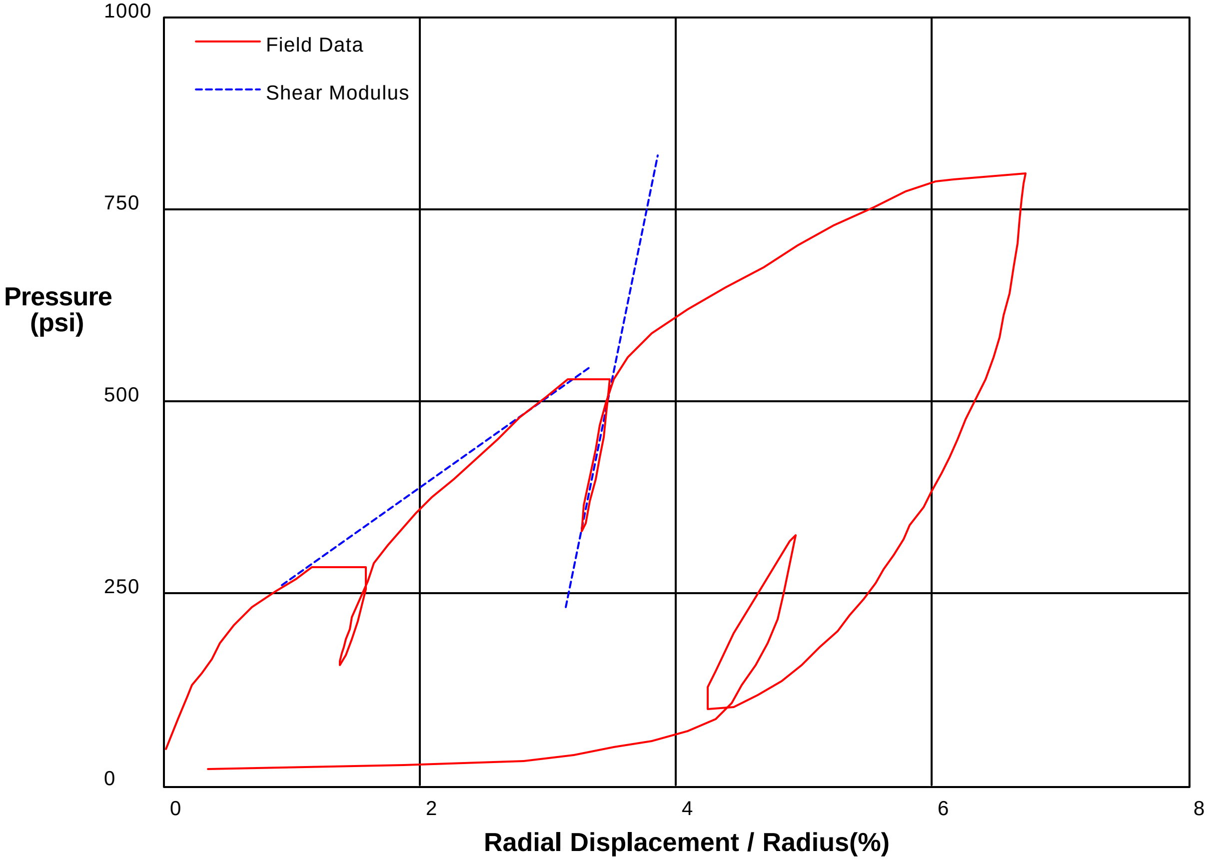
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 23, 2003**

Hole No. E-412 **Depth 173.5 ft** **File C:\DATA\C-268\BW34.P**



Shear Modulus 5890 psi

Shear Modulus 40942 psi

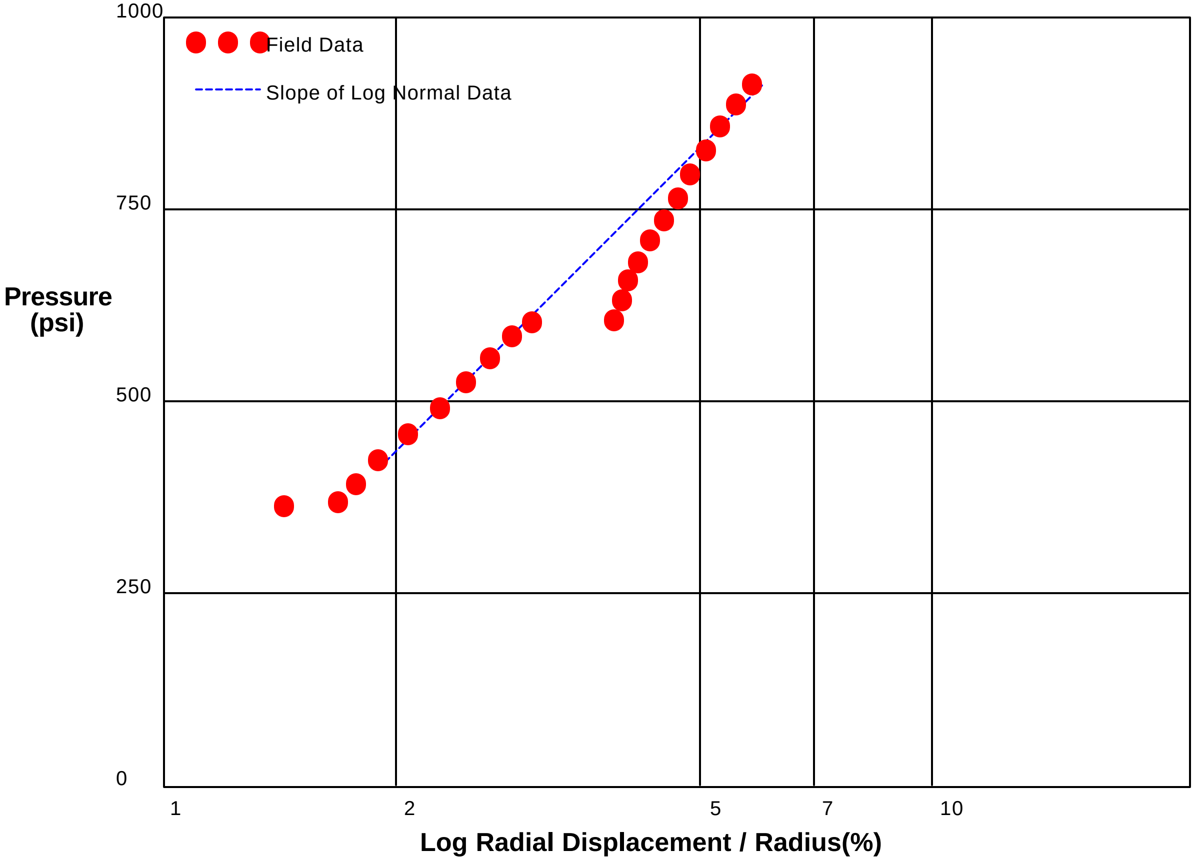
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 23, 2003**

Hole No E-412 **Depth 175 ft** C:\DATA\C-268\BW32.P



Shear Strength	**434.2 psi**
Limit Pressure	**1748 psi**

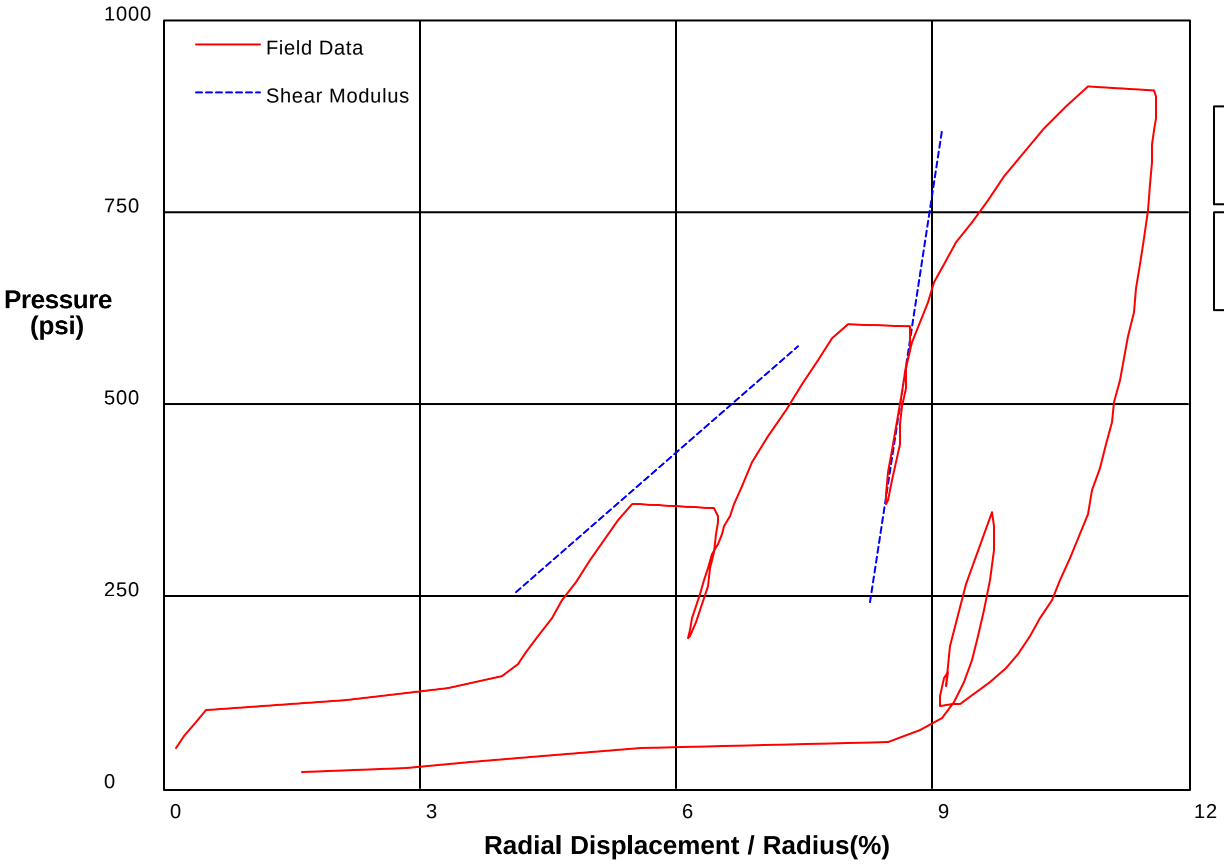
shift 5

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 23, 2003**

Hole No. E-412 **Depth 175 ft** **File C:\DATA\C-268\BW32.P**



Shear Modulus 4821 psi

Shear Modulus 36419 psi

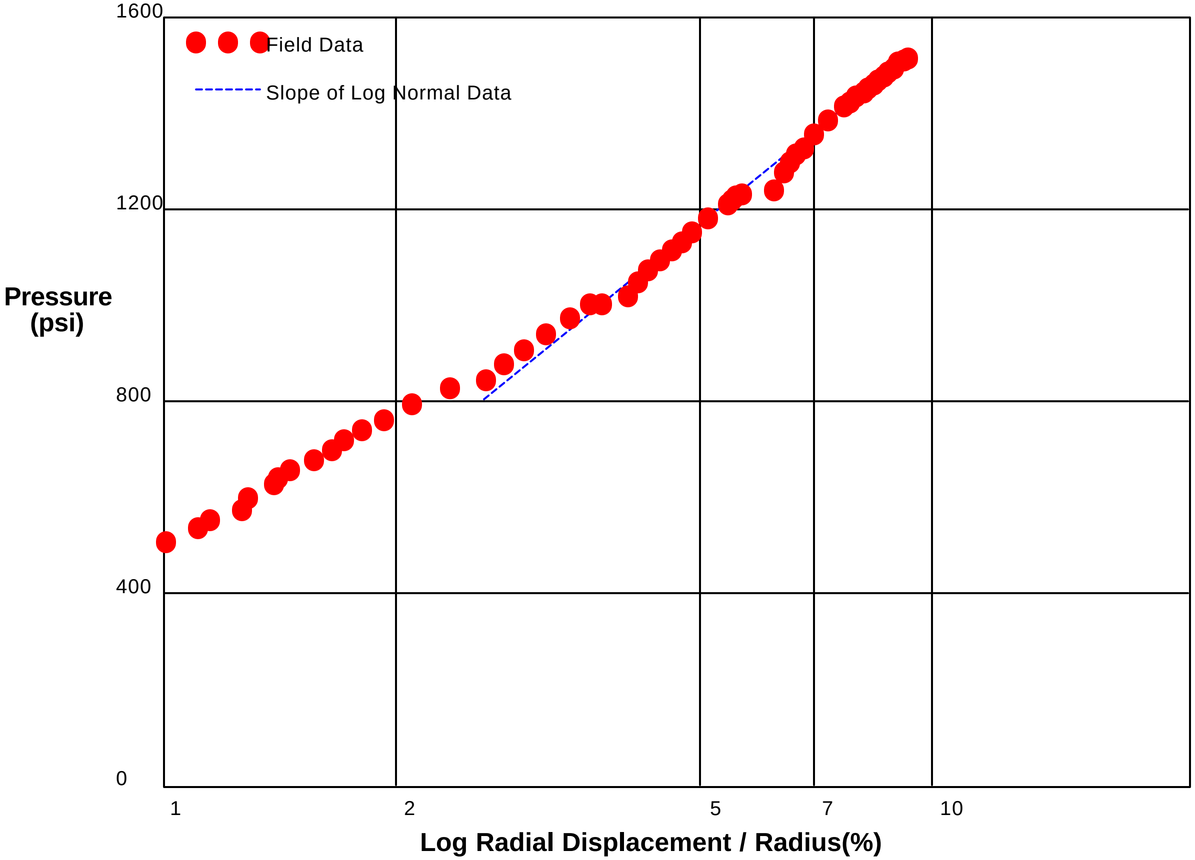
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 25, 2003**

Hole No E-412 **Depth 253.5 ft** C:\DATA\C-268\BW36COM.P



Shear Strength	**563.7 psi**
Limit Pressure	**2358 psi**

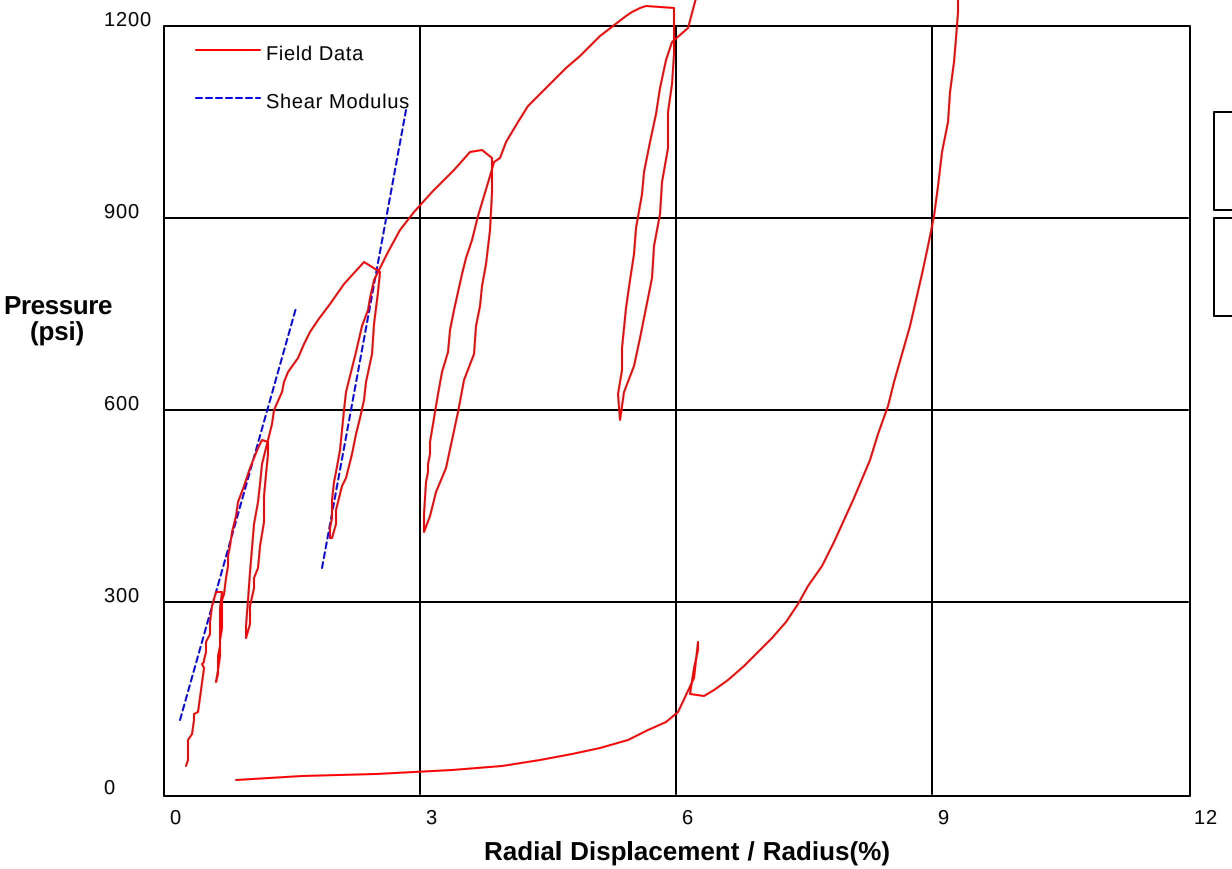
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 25, 2003**

Hole No. E-412 **Depth 253.5 ft** **File C:\DATA\C-268\BW36COM.P**



Shear Modulus 23678 psi

Shear Modulus 35833 psi

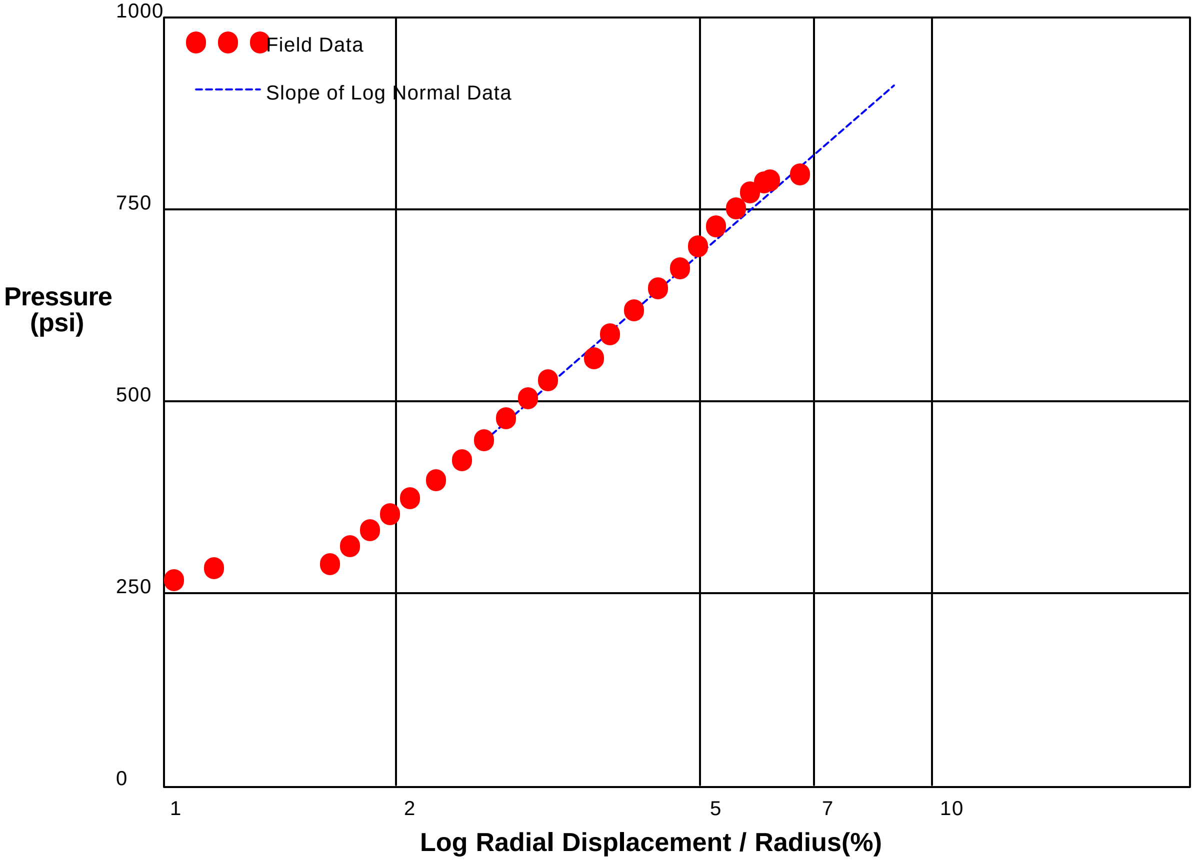
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 23, 2003**

Hole No E-412 **Depth 173.5 ft** C:\DATA\C-268\BW34.P



Shear Strength	**377.8 psi**
Limit Pressure	**1488 psi**

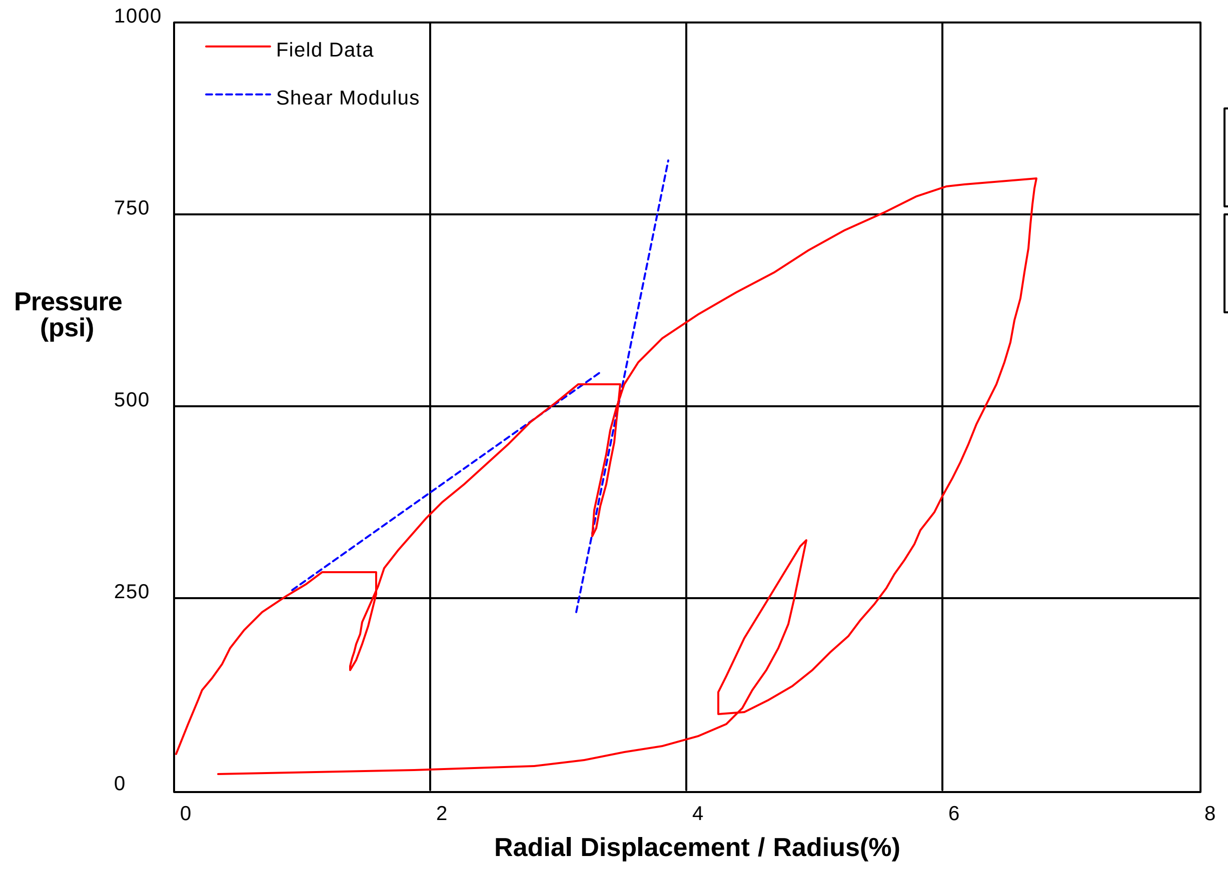
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 23, 2003**

Hole No. E-412 **Depth 173.5 ft** **File C:\DATA\C-268\BW34.P**



Shear Modulus 5890 psi

Shear Modulus 40942 psi

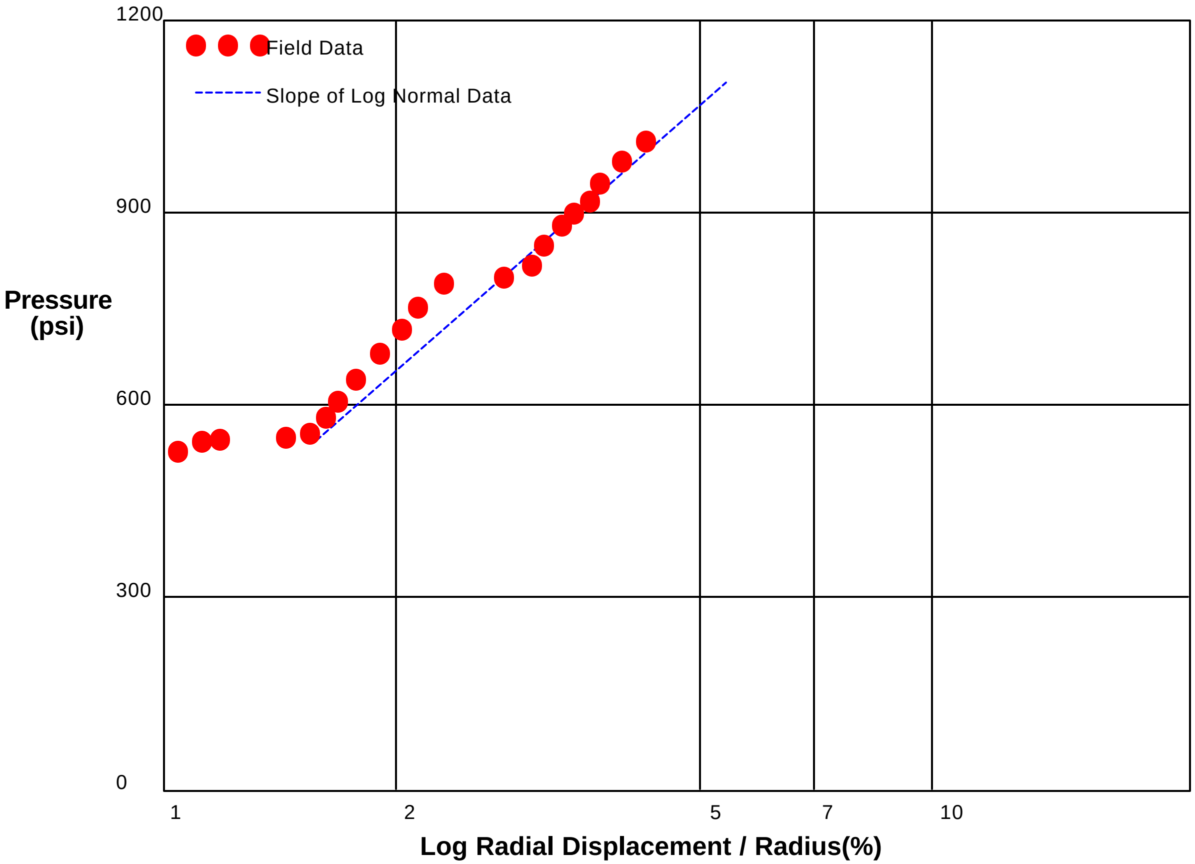
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 25, 2003**

Hole No E-412 **Depth 255 ft** C:\DATA\C-268\BW35.P



Shear Strength	**453.4 psi**
Limit Pressure	**2023 psi**

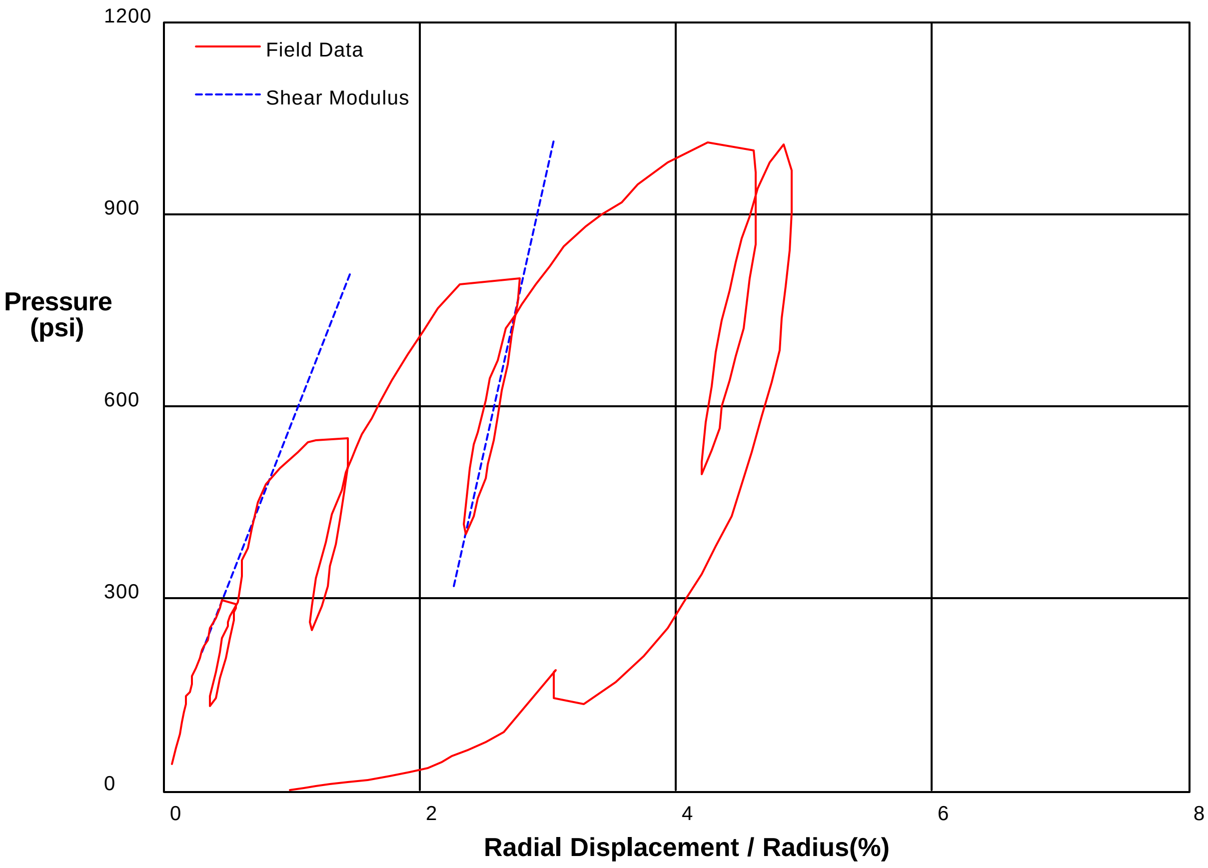
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 25, 2003**

Hole No. E-412 **Depth 255 ft** **File C:\DATA\C-268\BW35.P**



Shear Modulus 25357 psi

Shear Modulus 45135 psi

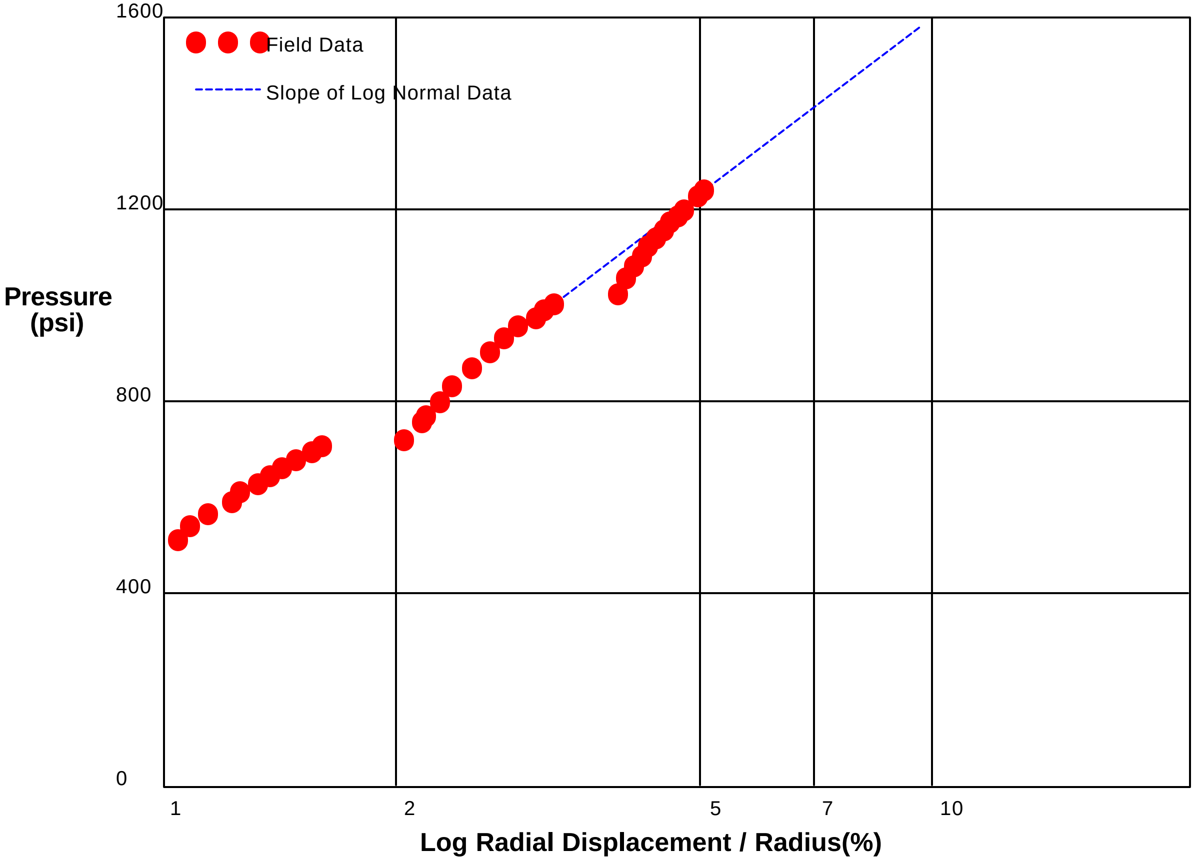
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 30, 2003**

Hole No E-414 **Depth 198 ft** C:\DATA\C-268\BW39.P



Shear Strength	**525.3 psi**
Limit Pressure	**2341 psi**

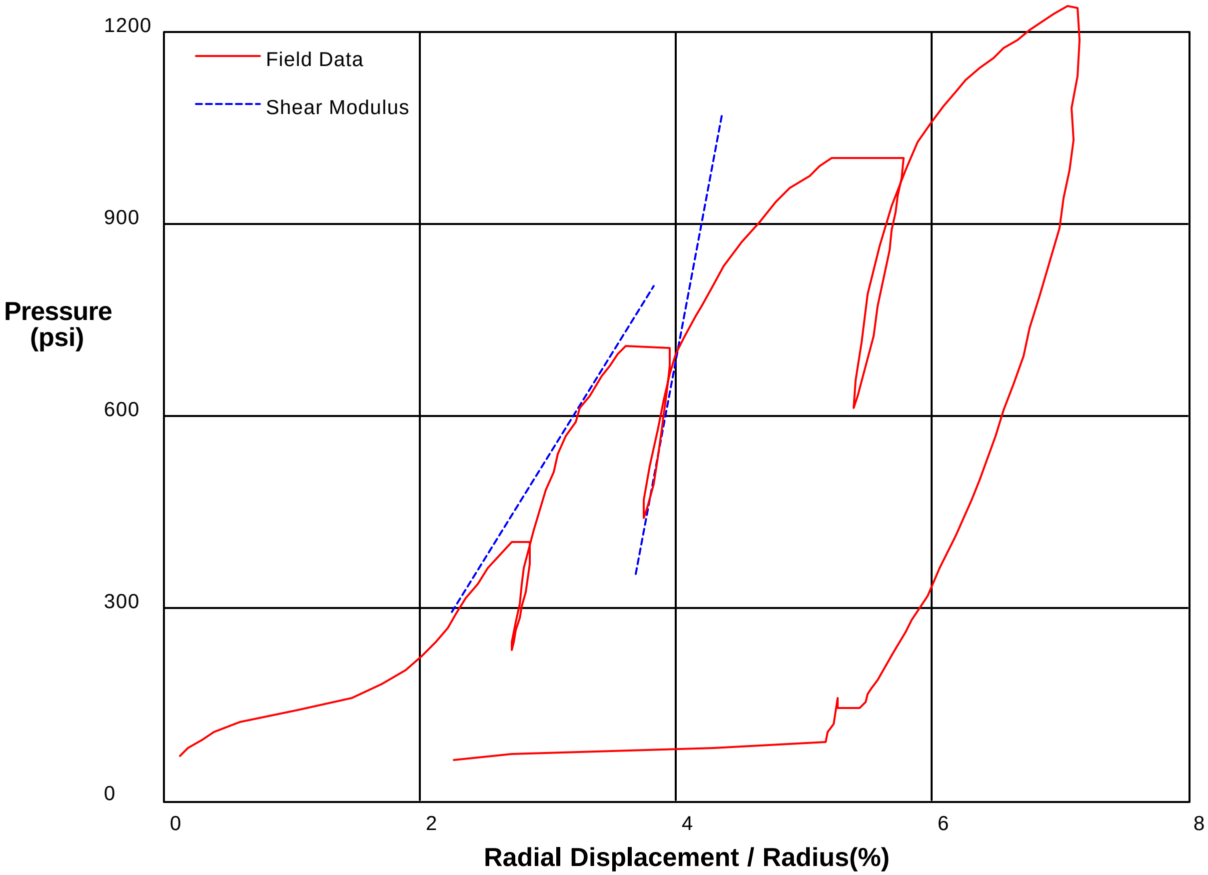
shift 2

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **July 30, 2003**

Hole No. E-414 **Depth 198 FT** **File C:\DATA\C-268\BW39.P**



Shear Modulus 16052 psi

Shear Modulus 53750 psi

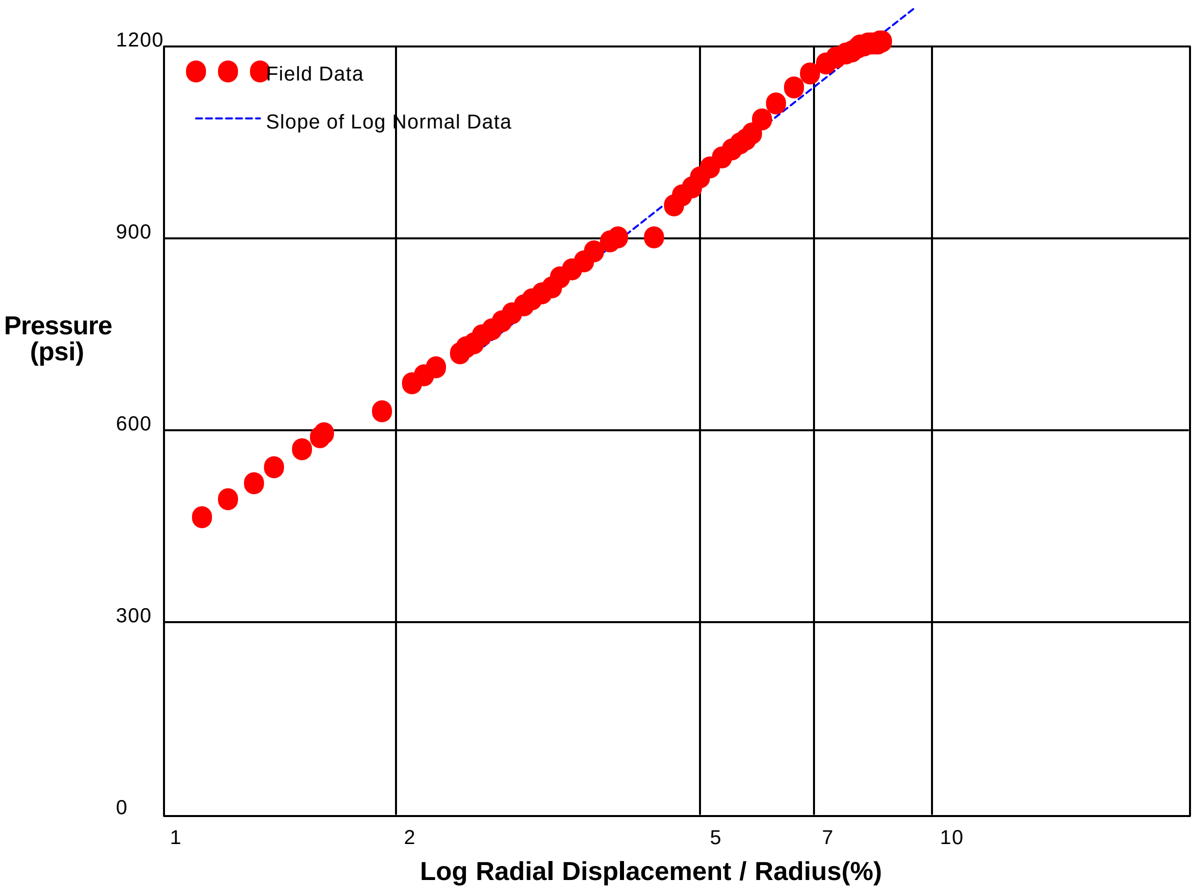
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **August 15, 2003**

Hole No E-416 **Depth 342.5 ft** C:\DATA\C-268\BW44.P



Shear Strength **408.2 psi**
Limit Pressure **1857 psi**

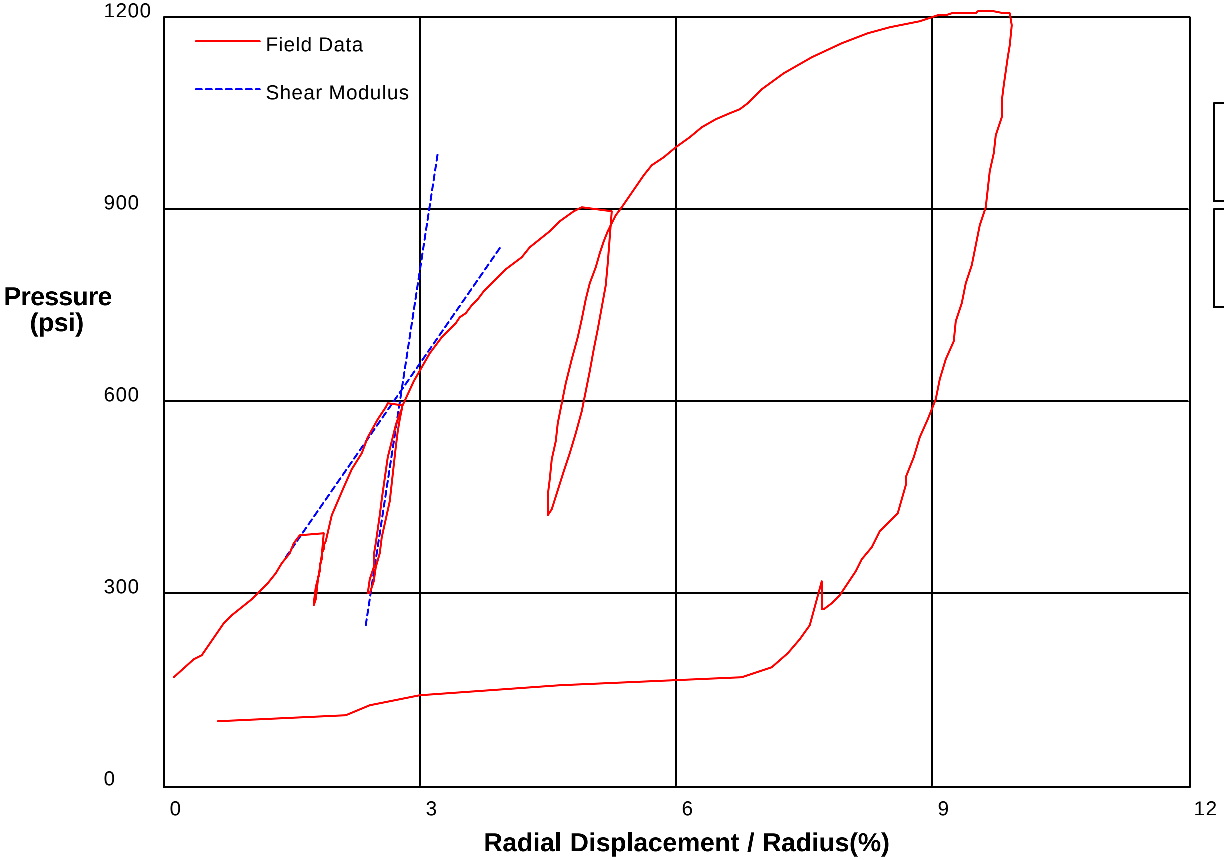
shift 1

HUGHES

PRESSUREMETER DATA Camp Dresser & McKee Inc.

King County Brightwater Project **August 15, 2003**

Hole No. E-416 **Depth 342.5 ft** **File C:\DATA\C-268\BW44.P**



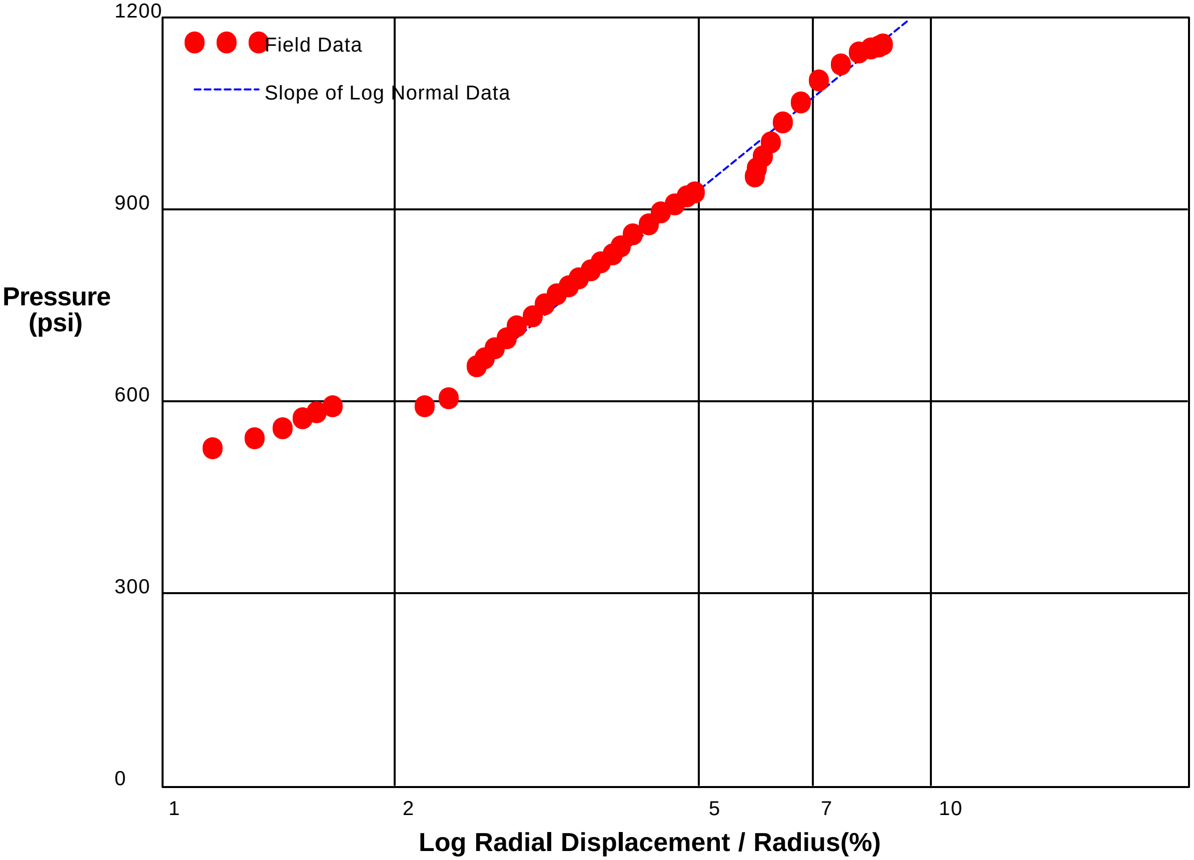
Shear Modulus 9629 psi

Shear Modulus 43703 psi

shift 0

HUGHES

PRESSUREMETER DATA	**Camp Dresser & McKee Inc.**	
King County Brightwater Project		**August 15, 2003**
Hole No E-416	**Depth 344 ft**	C:\DATA\C-268\BW43COM.P



Shear Strength	**422.8 psi**
Limit Pressure	**1822 psi**

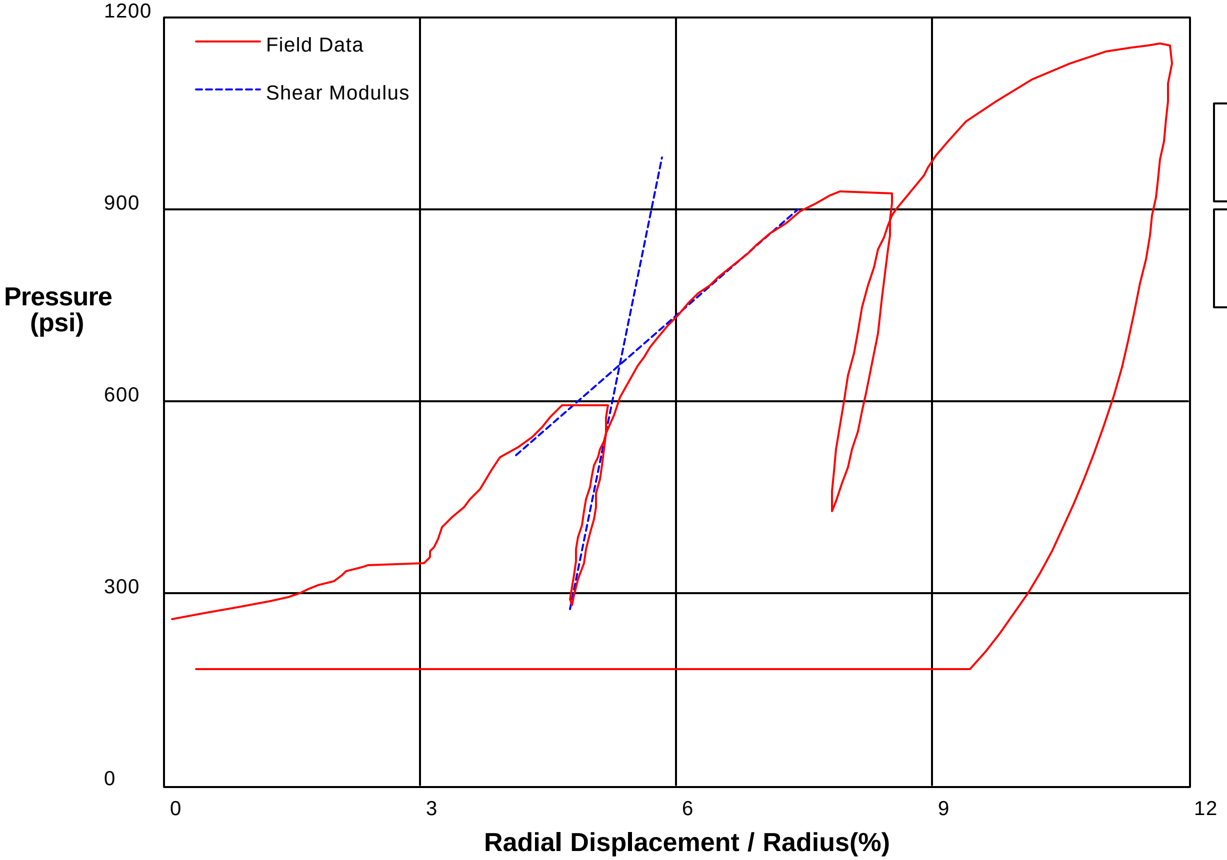
shift 4

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **August 15, 2003**

Hole No. E-416 **Depth 344 ft** **File C:\DATA\C-268\BW43COM.P**



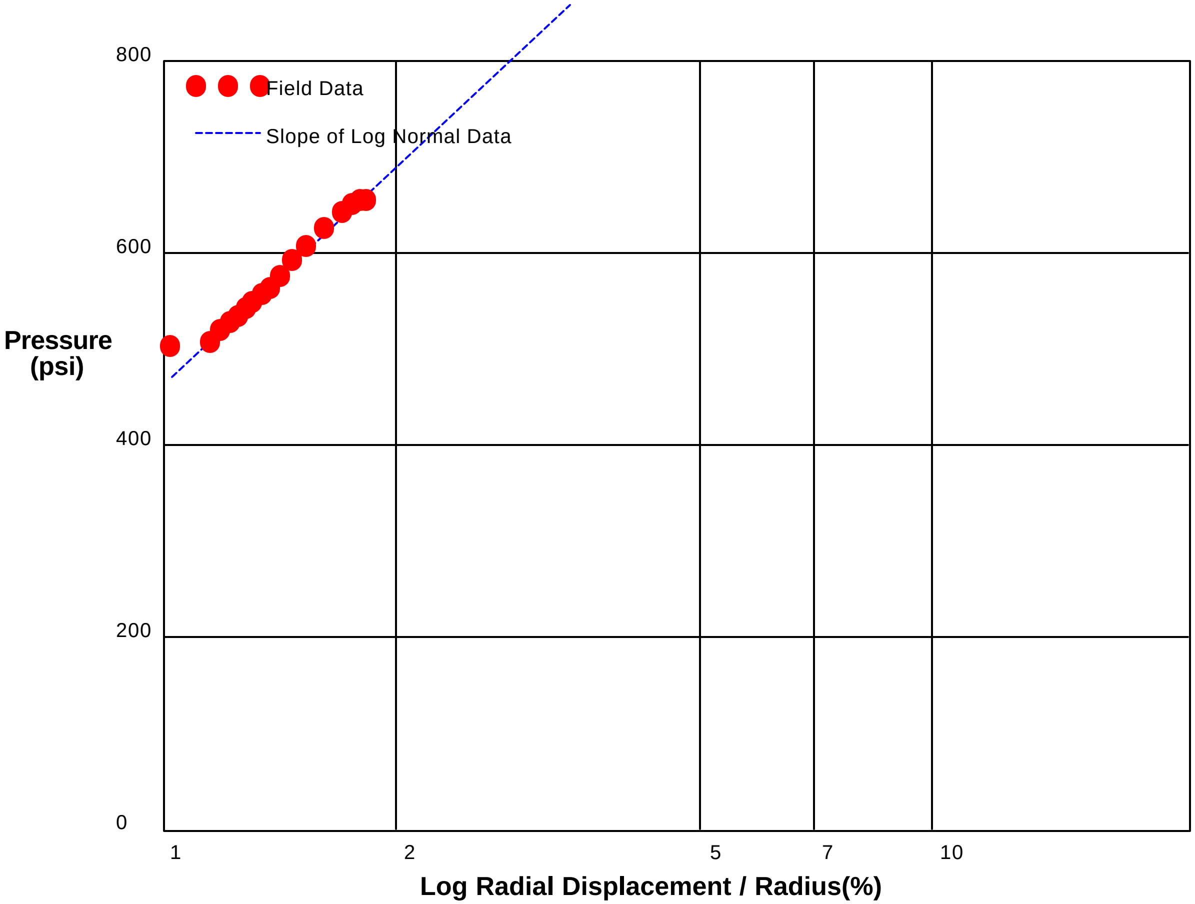
Shear Modulus 5786 psi

Shear Modulus 32753 psi

shift 1

HUGHES

PRESSUREMETER DATA	**Camp Dresser & McKee Inc.**	
King County Brightwater Project		**August 18, 2003**
Hole No E-416	**Depth 388 ft**	C:\DATA\C-268\BW46.P



Shear Strength	**324.1 psi**
Limit Pressure	**1668 psi**

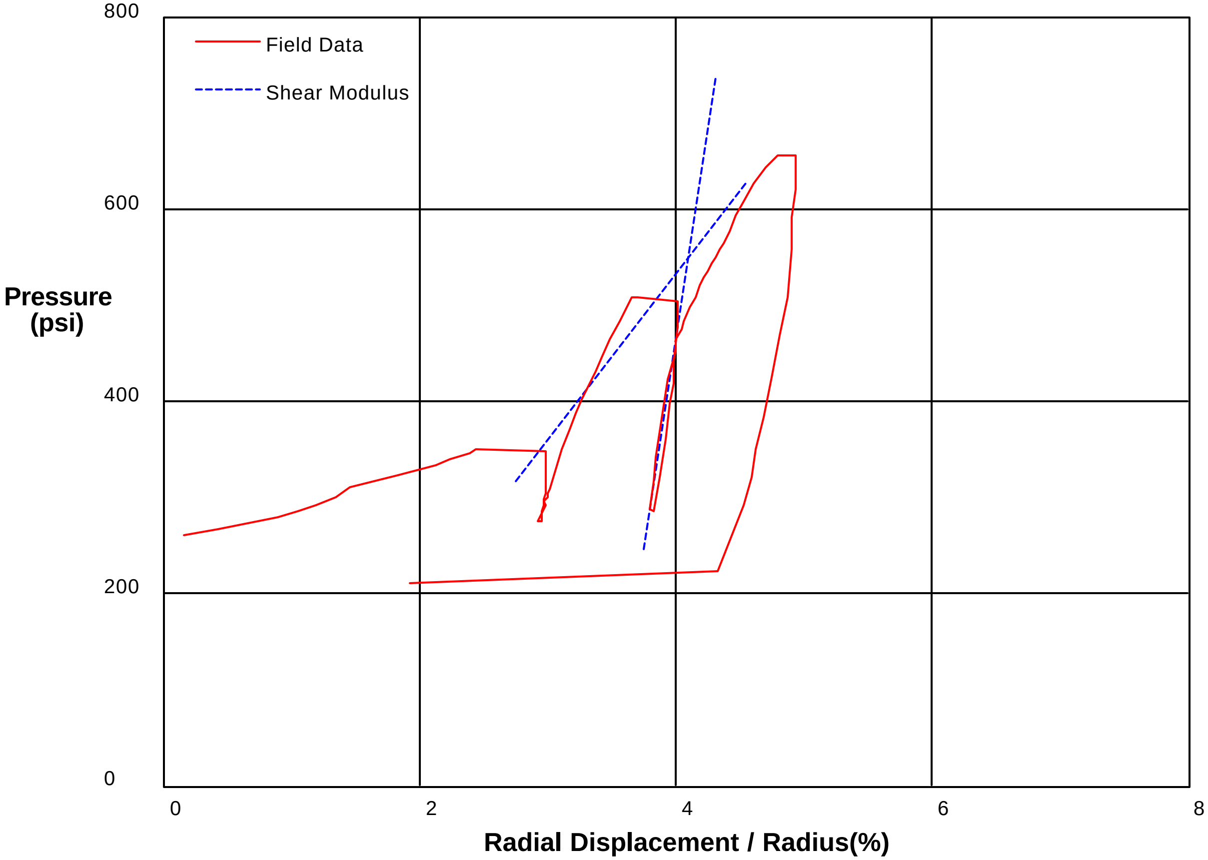
shift 9

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **August 18, 2003**

Hole No. E-416 **Depth 388 ft** **File C:\DATA\C-268\BW46.P**



Shear Modulus 8682 psi

Shear Modulus 43703 psi

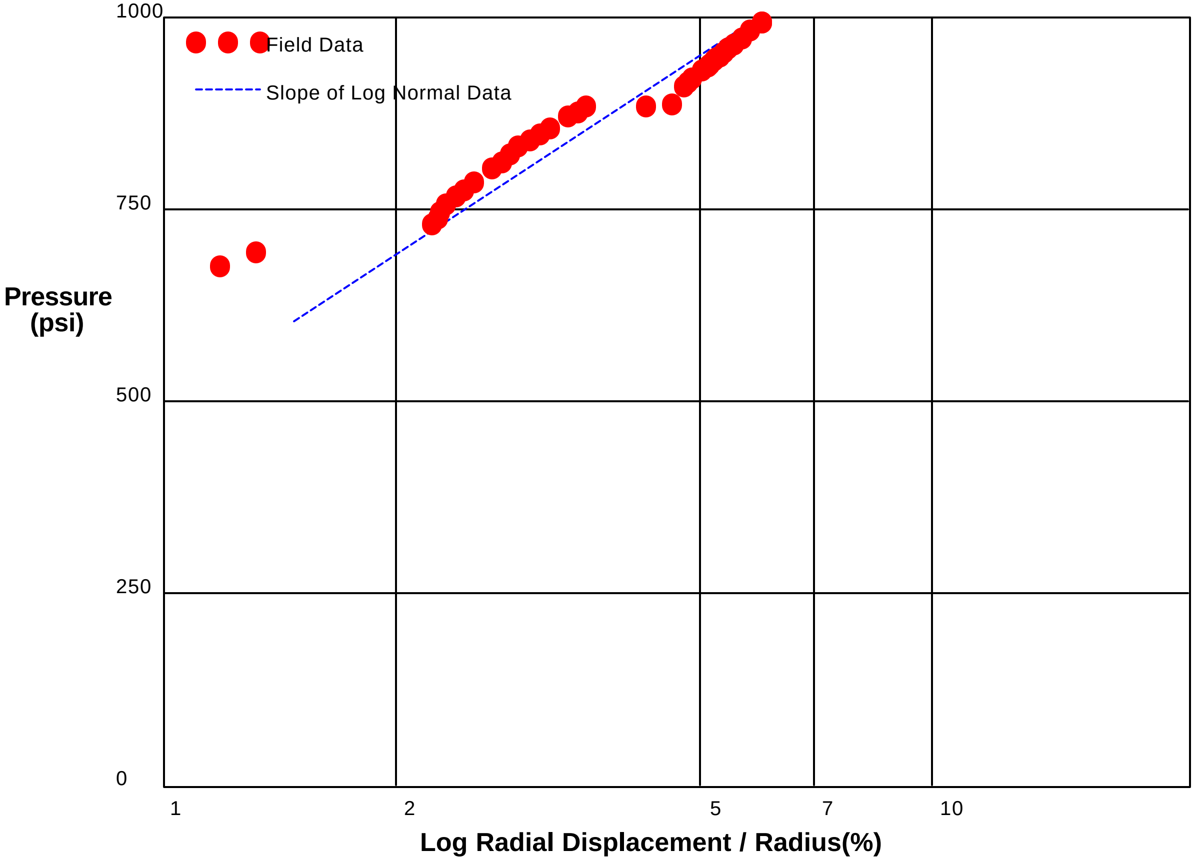
shift 6

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **August 18, 2003**

Hole No E-416 **Depth 389 ft** C:\DATA\C-268\BW45.P



Shear Strength	**284.5 psi**
Limit Pressure	**1549 psi**

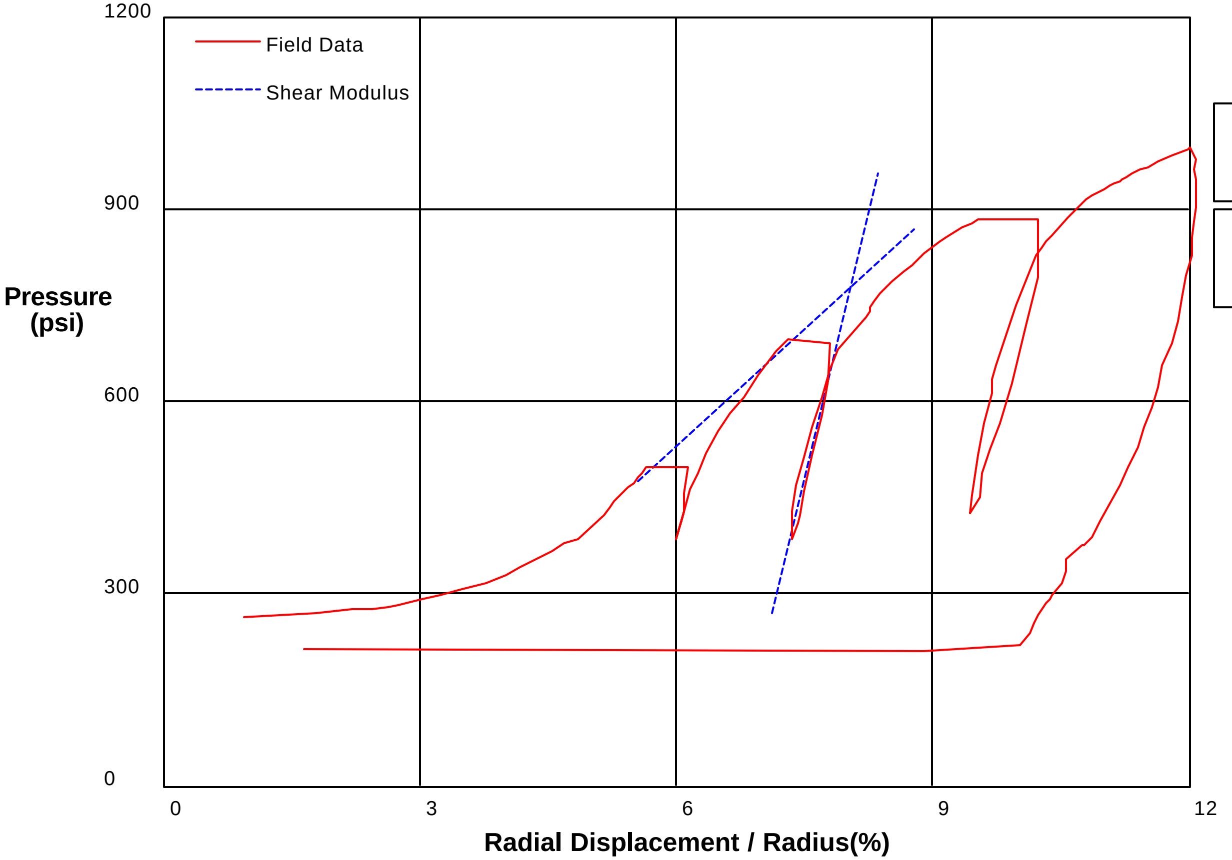
shift 8

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project **August 18, 2003**

Hole No. E-416 **Depth 389 ft** **File C:\DATA\C-268\BW45.P**



Shear Modulus 6086 psi

Shear Modulus 27763 psi

shift 2

HUGHES

Pressuremeter Testing

King County Brightwater Project Phase II Shaft Holes P41-02 and P44-02

submitted to

Camp Dresser & McKee Inc.,

11811 N.E. 1st Street, Suite 20
Bellevue, WA 98005

September 2004

C-287

HUGHES INSITU ENGINEERING INC.
Suite 804, 938 Howe Street, Vancouver B.C. Canada V6Z-1N9
Phone (604) 331-4451 Fax (604) 331-4452

CONTENTS

TABLE

FIGURES

PHOTOGRAPHS

APPENDIX
Basic pressuremeter data and interpretation plots

1.0 INTRODUCTION

This report outlines the results of a pressuremeter study, conducted August 10-12 in Hole P44-02 and August 23-27 in Hole P41-02 at the proposed shaft locations for the Brightwater Tunnels. The holes were drilled by Gregory Drilling Inc. Hughes Insitu Engineering Inc. performed the pressuremeter testing under the direction of Mr. D. Yonemitsu, the CDM Field representative.

2.0 OBJECT OF THE PRESSUREMETER INVESTIGATION

The object of this investigation was to determine the *in-situ* stiffness and strength, and get some indication of the lateral stress at these shaft locations.

3.0 PRESSUREMETER

The pressuremeter used for this study is a monocell pressuremeter. At the center of the pressuremeter are three electronic displacement sensors, spaced 120 degrees apart. Over these sensors is the flexible membrane, clamped at each end, which is pressurized to deform the adjacent material. A protective sheet of stainless steel strips covers the membrane. The pressuremeter was expanded by regulating the flow of gas from a bottle of compressed nitrogen. The electronic signals from displacement sensors and the pressure sensor are transmitted by cable to the surface. During the test, the average expansion against pressure curve is displayed on a computer screen.

The essential details of the instrument are shown in Fig. 1.

4.0 HOLE FORMATION

Hole P44-02

A six-inch diameter uncased mudded hole was advanced to the test level. At this hole the materials were predominantly granular with few fines. Hence, just forming a stable hole in this material proved particularly difficult. The pilot hole for the pressuremeter, which has to be close to three inches in diameter, is usually cut with a $2^{15}/16$-inch diameter tricone bit. This method was attempted at the first test location at the 30 ft level. However, in these relatively clean granular materials, this method was not very successful. The resulting hole was washed oversize. As the blow count was still relatively low, an attempt was made to cut the next pilot hole at the 37 ft level by driving a three-inch SPT spoon. At this level a layer of silt/clay (possibly an old Paleolithic ground surface) was encountered. The SPT method of forming a pilot hole was successful, although the data seemed to suggest that the hole, although stable, was undersize.

Below that depth, the silt content decreased and the gravel content increased. Further, the material became dense with blow counts exceeding 100. In these materials, that were too dense to drive a three-inch SPT to form a pilot hole, the only remaining method was to use a tricone bit. The pressuremeter test pockets were then only attempted when it was estimated that the silt content was sufficient to form a stable hole. Two tests were completed in this manner, at 115 and 125 ft. In all six tests were attempted, of which three gave useful data.

Hole P41-02

The materials in this hole were recent granular materials with little silt content. As with Hole P44-02 the open hole was very difficult to keep stable. On several occasions sections collapsed. There were strong indications of gravel from the recovery in the SPT barrel. However this may have been from material washed down the hole from some higher level. Although the material was less dense than at the P44-02 site (with a blow count in the order of 20 to 30) it was felt that this was too dense to drive the three inch SPT with the hammer available. The three-inch diameter pilot hole was drilled with a $2^{15}/16$-inch diameter tricone bit. With that method, data was collected at three locations.

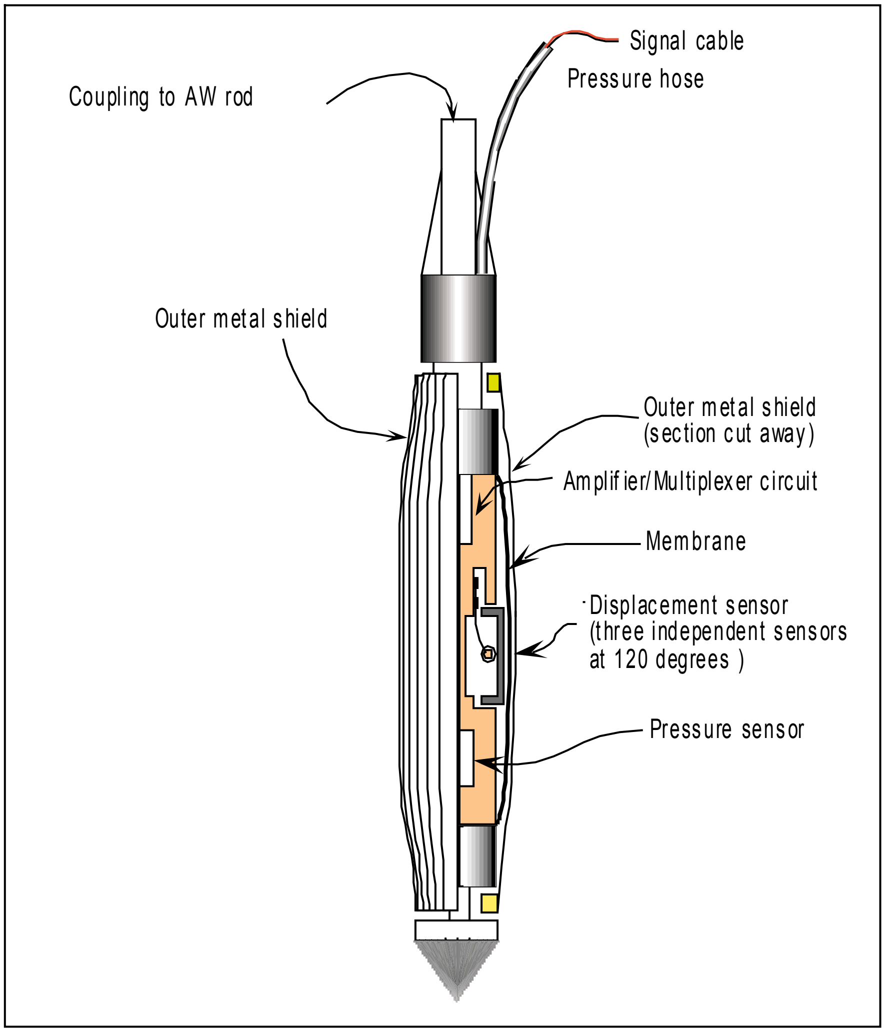


Fig. 1. Schematic outline of pressuremeter

Photograph 1. Gregory Drilling Inc. on location at Hole P44-02

Photograph 2. Gregory Drilling Inc. on location at Hole P41-02

5.0 TEST PROCEDURE

After the pressuremeter was inserted to the bottom of the hole, the membrane was expanded by controlling the flow of compressed nitrogen into the pressuremeter, increasing the pressure in small steps. The pressure was increased until one of the strain sensors reached a limit.

During this expansion several unload-reload loops were conducted to determine the low strain shear modulus. Prior to each unload cycle, the pressure was held constant for four minutes to obtain a qualitative indication of the creep behavior of the matrix.

If the material surrounding the pressuremeter is assumed to extend to infinity, and to behave in an idealized manner, as a linear elastic, homogeneous material, which does not fail under shear or tension, then the displacement on the boundary of the pressuremeter, $u_{"}$, for a given pressure, P, is given by:

$$U_a = \text{P.a}\ (1+\text{m}) / E \qquad 1)$$

where E is the Young’s Modulus, a the radius of the pressuremeter cavity, and μ the Poisson’s ratio.

As the shear modulus, G, and the Young’s modulus, E, are related by the following relationship:

$$E=2.G.(1+\text{m}) \qquad 2)$$

Equation 1 reduces to:

$$U_a = 0.5P.\text{a} / G \qquad 3)$$

Hence, the shear modulus G is given by:

$$\text{G} = 0.5\,)\,\text{(Pressure)/}\,)\,\text{(radial displacement/radius)} \qquad 4)$$

The pressuremeter data is often characterized by the modulus determined from the initial slope of the pressuremeter curve. In many instances this is not clearly defined, as the pressuremeter curve does not always show a distinct linear section near the start. Hence, the choice of the initial modulus is subjective. The shear modulus values for the average slope of the initial part of the pressuremeter curve of all of the tests are summarized in Table 1. The modulus for the average slope of the pressuremeter curve expressed as a Young’s modulus (assuming a Poisson's ratio of 0.33) is the same as the “pressuremeter modulus” defined in the American Society for Testing and Materials (ASTM) D4719-94, Section 9.5. Also included in Table 1 is the modulus determined from any unload-reload loops. This modulus is much more clearly defined and can be used to give an indication of the true elastic properties of the material.

6.0 STANDARD PRESSUREMETER PARAMETERS

Limit pressure and shear strength

As a quantitative measure of the strength of the material, the "limit pressure", P_L, is commonly used. This is the pressure, which is calculated to occur when the pressuremeter has been assumed to deform the material by doubling the initial volume of the cavity. If the material being tested is assumed to behave as an elastic cohesive material, then the equation governing the pressure-displacement curve is given by:

$$P = P_L + c.\log_e (u_a/a) \qquad 5)$$

where P_L is the theoretical limit pressure at infinite expansion.

$$P_L = P_o + c + c.\log_e [G/c] \qquad 6)$$

Here, c is the undrained cohesive strength, P_O is the total *in-situ* lateral stress, and G the shear modulus. For typical values of G and c the ratio G/c lies between 50-100. Hence, the limit pressure is approximately 5 times the shear strength (assuming P_o is small relative to c).

From Equation 5, a plot of pressure P against the log of u_a/a will be a straight line, provided the shear strength remains constant with strain. The slope of this line will give a measure of the shear strength c. The limit pressure, as defined by the ASTM code D4719, Section 9.6, is the pressure at which the cavity has doubled in size. This doubling in size occurs when u_a/a is equal to 41%. (The origin of the strain used in the log/normal plots is the assumed origin at the *in-situ* stress state).

The shear strengths calculated by this method for Seattle materials are usually an overestimate of the *in-situ* shear strength. Therefore, they have not been reported in Table 1.

7.0 MODEL METHOD OF ANALYSIS

As an alternative method of analysis, an ideal pressuremeter curve can be developed, based on fundamental material parameters, which can then be compared to the field data. Adjustments can then be made to the model parameters, such that the ideal pressuremeter curve and the model curve match. The ideal pressuremeter curve is a function of the assumed material model. If the material is assumed to behave as a cohesive material, the required parameters are the cohesive strength, initial secant modulus and the total *in-situ* stress. If the material behaves in a predominantly frictional manner, the friction angle, rather than cohesion, is a necessary parameter together with the effective lateral stress.

In the cohesive materials the final unloading can be analyzed to give another indication of the shear strength. The shear strength determined from the unloading curve will, in an ideal homogeneous material, be twice the undrained shear strength. This occurs because the unloading curve represents material that is initially failing while moving outwards which then reverses failure to move inwards. If the material behaves the same in both directions, then the shear strength determined from the unloading curve will be twice the loading shear strength. As it is likely that the material will be stronger on initial loading, than on unloading the shear strength derived from the unloading analysis will give a conservative estimate of the strength.

8.0 COMMENTS ON THE RESULTS

In view of the difficult ground conditions, the data from this investigation in both the holes is limited. However, the tests are consistent with the SPT data. The material at Hole P44-02 is denser than at Hole P41-02. In the one clay zone at 37 ft in Hole P44-02, the lateral stress seems to indicate an overconsolidated material. In view of the disturbance, the friction and the lateral stress cannot be assessed with any accuracy. In the analysis presented in Table I for Hole P44-02, two different friction angles have been used to determine the range of the lateral stress. The results of this analysis indicate that the lateral stress in the lower sand layers appears to be lower than in the clay. The results of the analysis for the friction angle and lateral stress for Hole P41-02 indicate a very loose unstable material. This result is not quite as expected from the SPT data. Hence, the pressuremeter results may have been adversely influenced by the disturbance caused during drilling.

9.0 REFERENCES

Mair, R.J., and Wood, D.M. 1987. Pressuremeter testing: methods and interpretation. CIRIA Ground Engineering Report. Butterworths, London.

ASTM D4719. 1994. Standard test method for pressuremeter testing in soils.

Table 1. Basic material properties from derived from the pressuremeter tests

File Number	**Hole**	**Depth (feet)**	**Initial shear modulus (psi)**	**Unload-reload Shear modulus (psi)**	**Limit Pressure (psi)**	**Cohesion (psi)**	**Friction angle**[3]	**Lateral stress (psi)**
CDM2Z	P44-02	37.5	700	14,000	450	70-(36)[1]	-	50 [2]
CDM3Z	P44-02	115	3,000	30,000	800	-	36 [5]	40 [3]
							40 [5]	25 [3]
CDM5Z	P44-02	123.5	6,000	22,000	850	-	38 [5]	40 [3]
							40 [5]	36 [3]
CDM7Z	P41-02	62.5	140	5,000	110	-	33 [5]	6 [3,4]
CDM8Z	P41-02	71.5	450	9,000	220	-	34 [5]	10 [3,4]
CDM9Z	P41-02	92.5	600	9,000	300	-	34 [5]	20 [3]

Notes

[1] This tests indicate a material that is primarily cohesive. The analysis of the loading curve gives a shear strength in the order of 70 psi whereas the unloading curve gives an undrained strength of (75/2) psi. The total lateral stress is indicative of an overconsolidated material.

[2] Total lateral stress in the cohesive material.

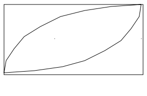
[3] Effective lateral stress

[4] The effective lateral stress is lower than might have been anticipated from the blow count. Therefore there is a question as to whether the material is indeed very loose and the blow counts have been influenced by the gravel or the test are dominated by slough in the hole.

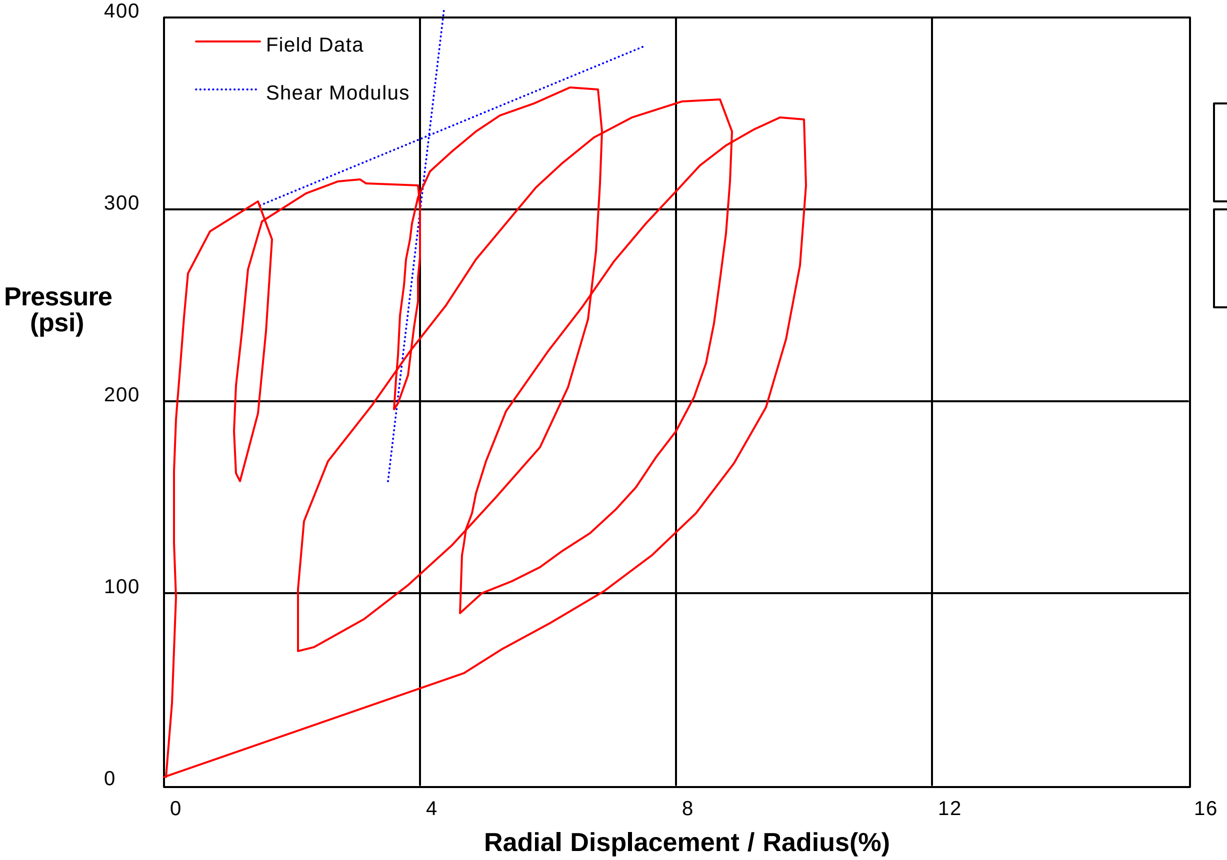
[5] These tests are on granular material with little silt content.

Appendix

Pressure-expansion curves for pressuremeter tests



PRESSUREMETER DATA	**Camp Dresser & McKee Inc.**	
King County Brightwater Project Phase II		**August 10, 2004**
Hole No. P44-02	**Depth 37.5 ft**	**File C:\DATA\C-287\CDM2Z.P**



Shear Modulus 14047 psi

Shear Modulus 686 psi

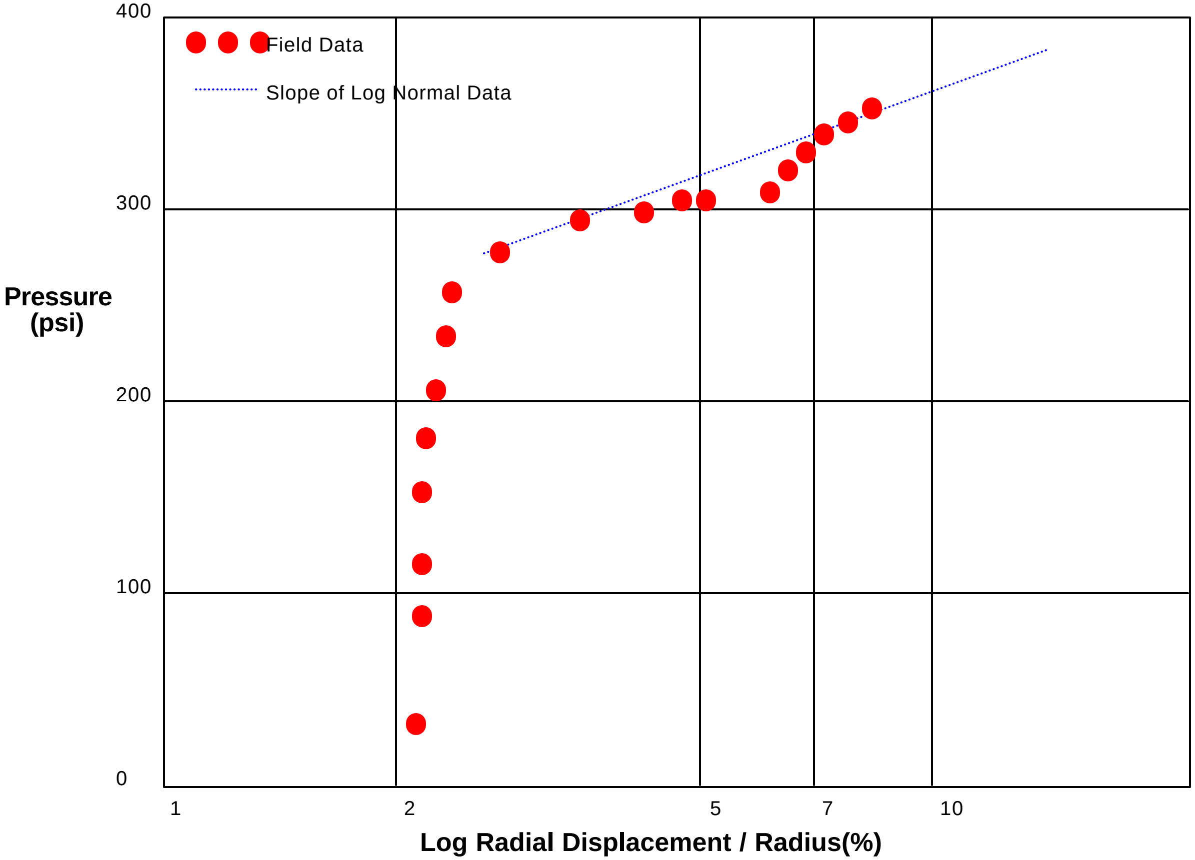
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project Phase II **August 10, 2004**

Hole No. P44-02 **Depth 37.5 ft** **File C:\DATA\C-287\CDM2Z.P**



Shear Strength 62.8 psi
Limit Pressure 450 psi

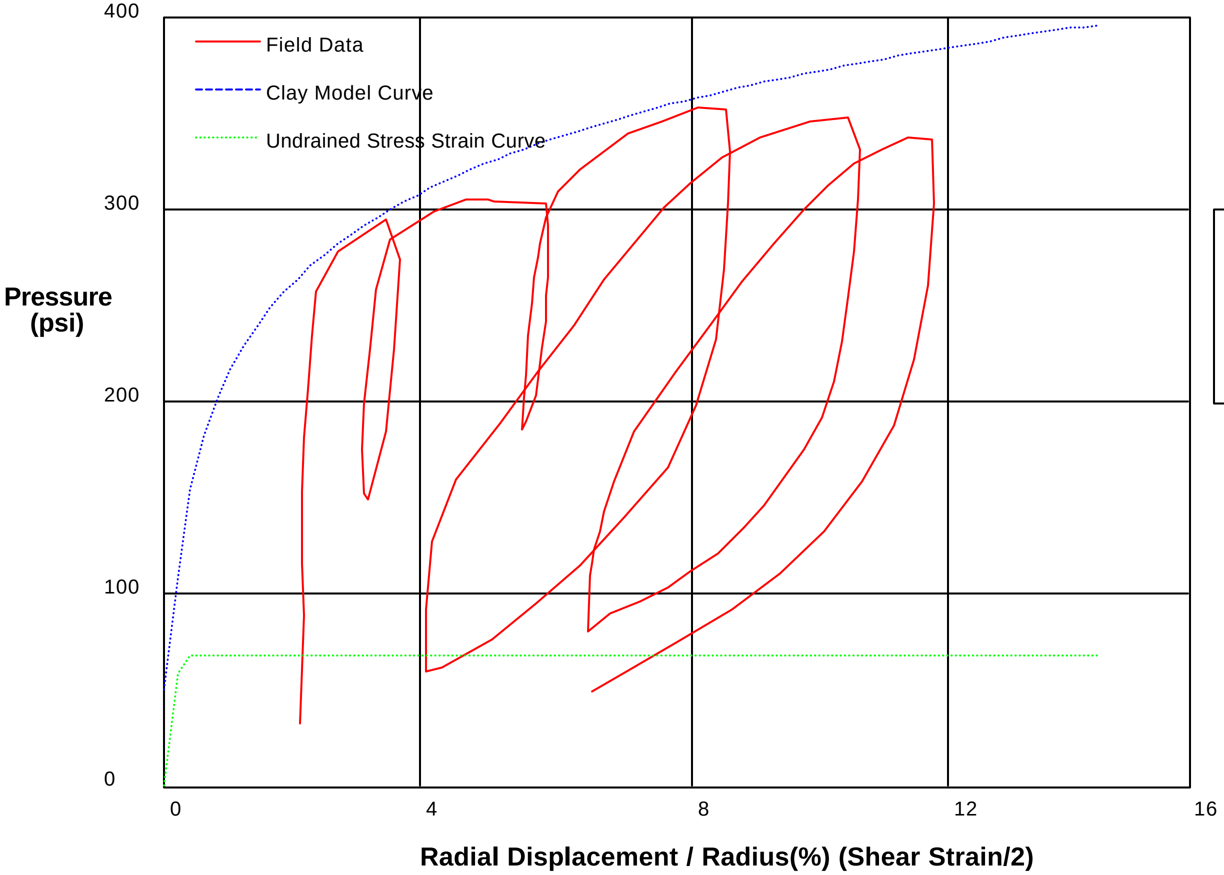
shift-2

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project Phase II **August 10, 2004**

Hole No. P44-02 **Depth 37.5 ft** **File C:\DATA\C-287\CDM2Z.P**



GIBSON'S CLAY MODEL

Shear Strength	**68**	**psi**
Insitu Stress	**50**	**psi**
Shear Modulus	**14000**	**psi**

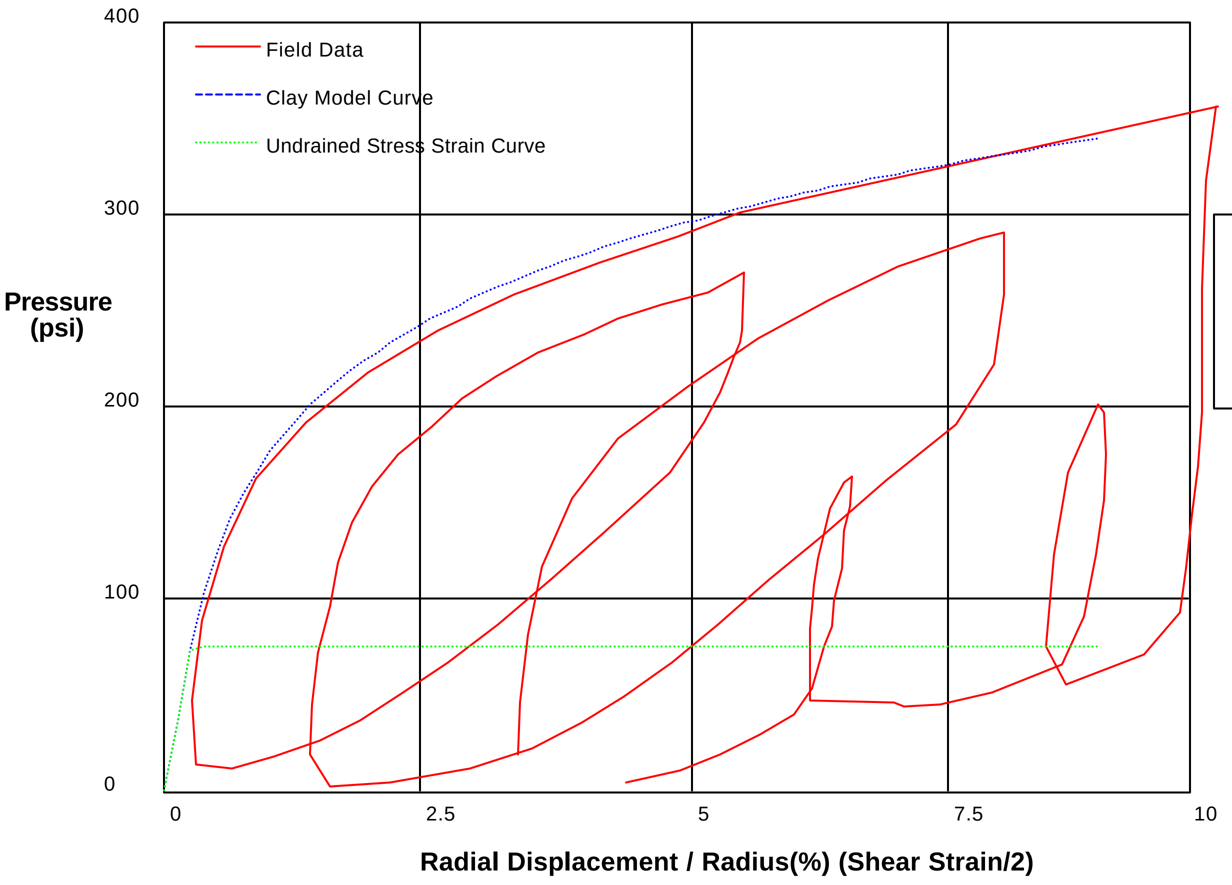
shift-2

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project Phase II **August 10, 2004**

Hole No. P44-02 **Depth 37.5 ft** **File C:\DATA\C-287\CDM2Z.P**



GIBSON'S CLAY MODEL

Shear Strength **75 psi**
Insitu Stress **0 psi**
Shear Modulus **14000 psi**

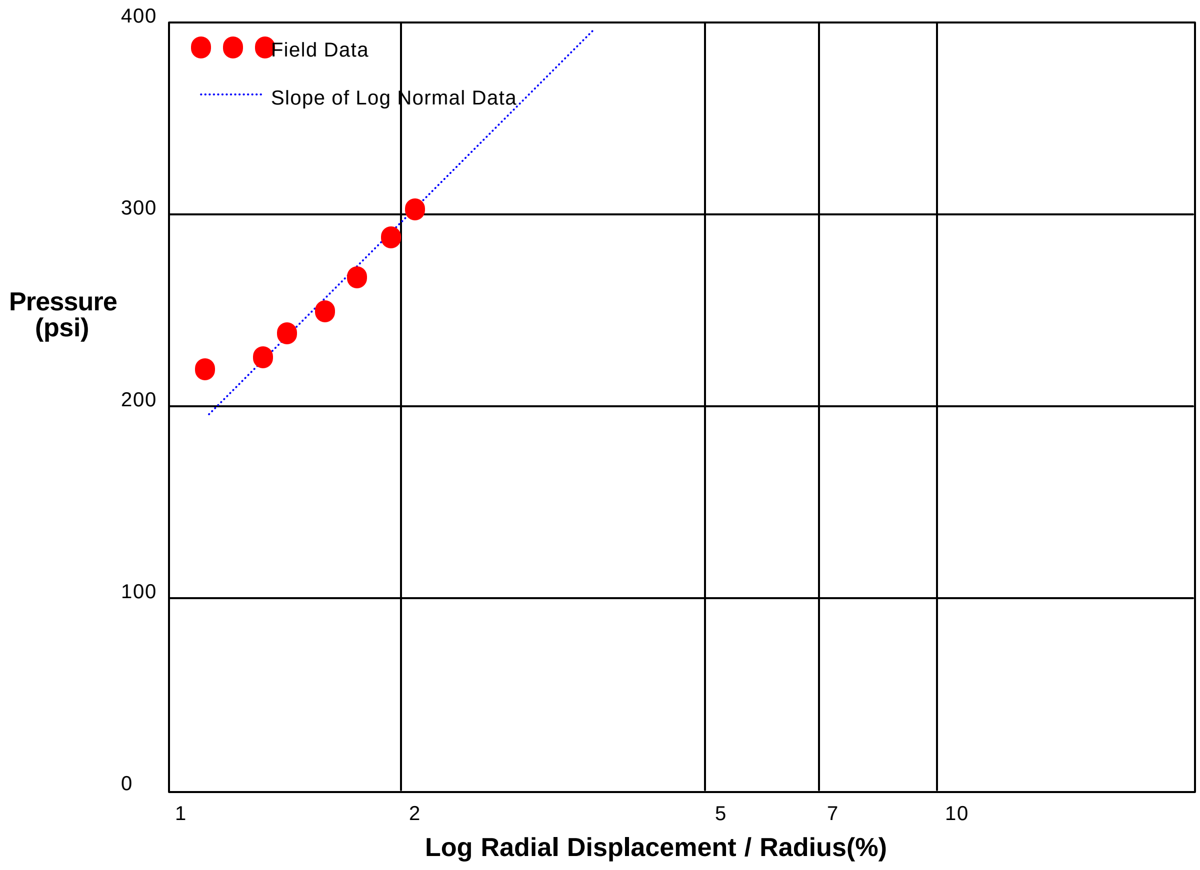
shift 9.7

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project Phase II **August 12, 2004**

Hole No. P44-02 **Depth 115 ft** **File C:\DATA\C-287\CDM3Z.P**



Shear Strength 173.7 psi
Limit Pressure 820 psi

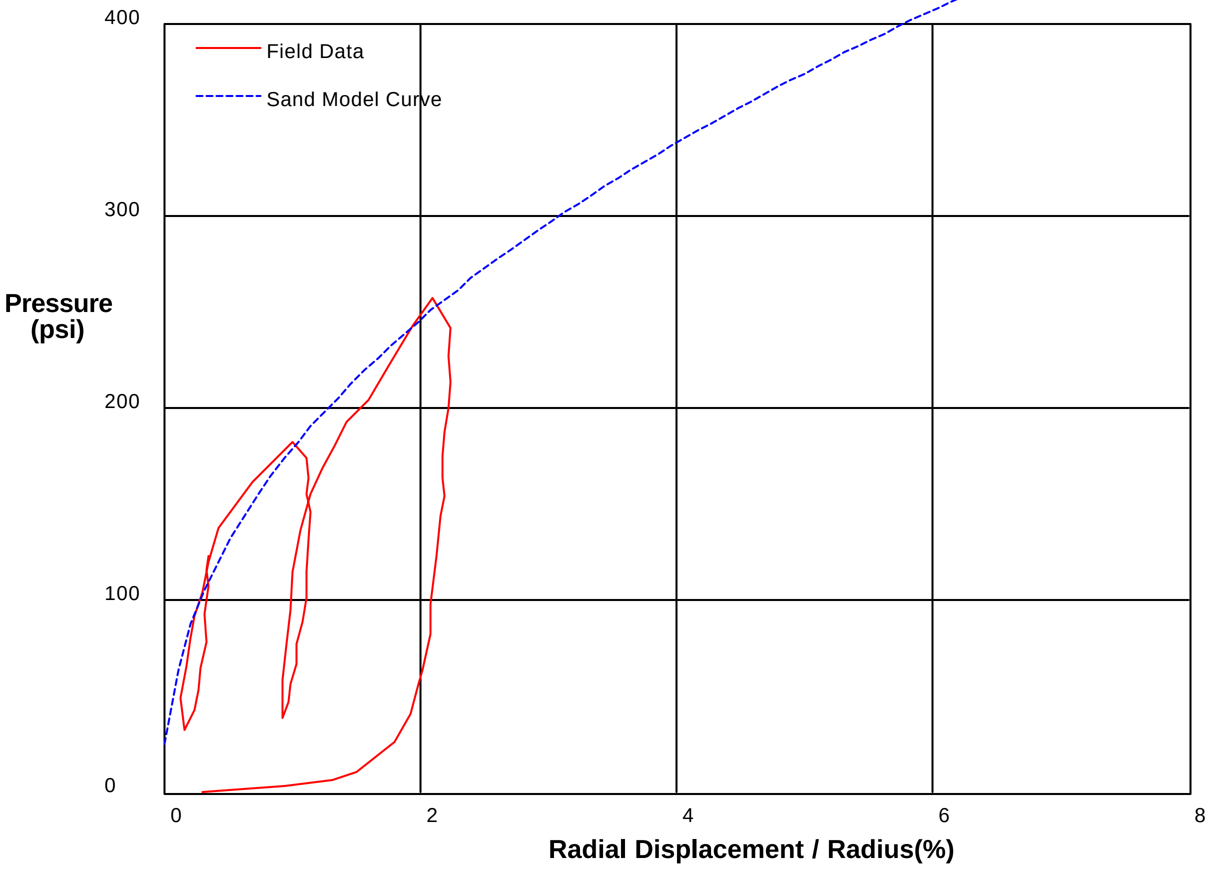
shift 13.5

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project Phase II **August 12, 2004**

Hole No. P44-02 **Depth 115 ft** **File C:\DATA\C-287\CDM3Z.P**



THE HUGHES SAND MODEL

Water Pressure	**46 psi**
Friction Angle	**40 deg**
Critical Friction Angle	**32 deg**
Lateral Stress	**25 psi**
Shear Modulus	**20000 psi**

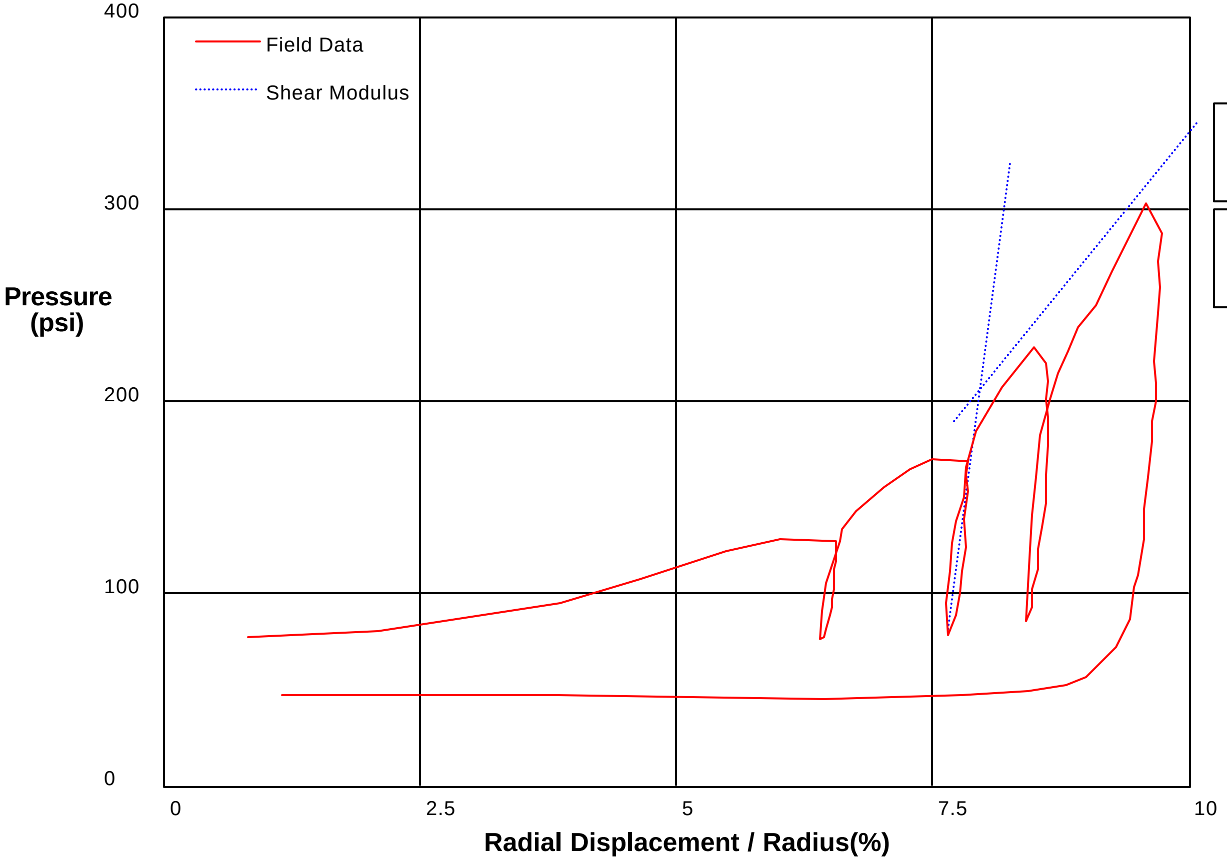
shift 13.5

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project Phase II **August 12, 2004**

Hole No. P44-02 **Depth 115 ft** **File C:\DATA\C-287\CDM3Z.P**



Shear Modulus 19801 psi

Shear Modulus 3246 psi

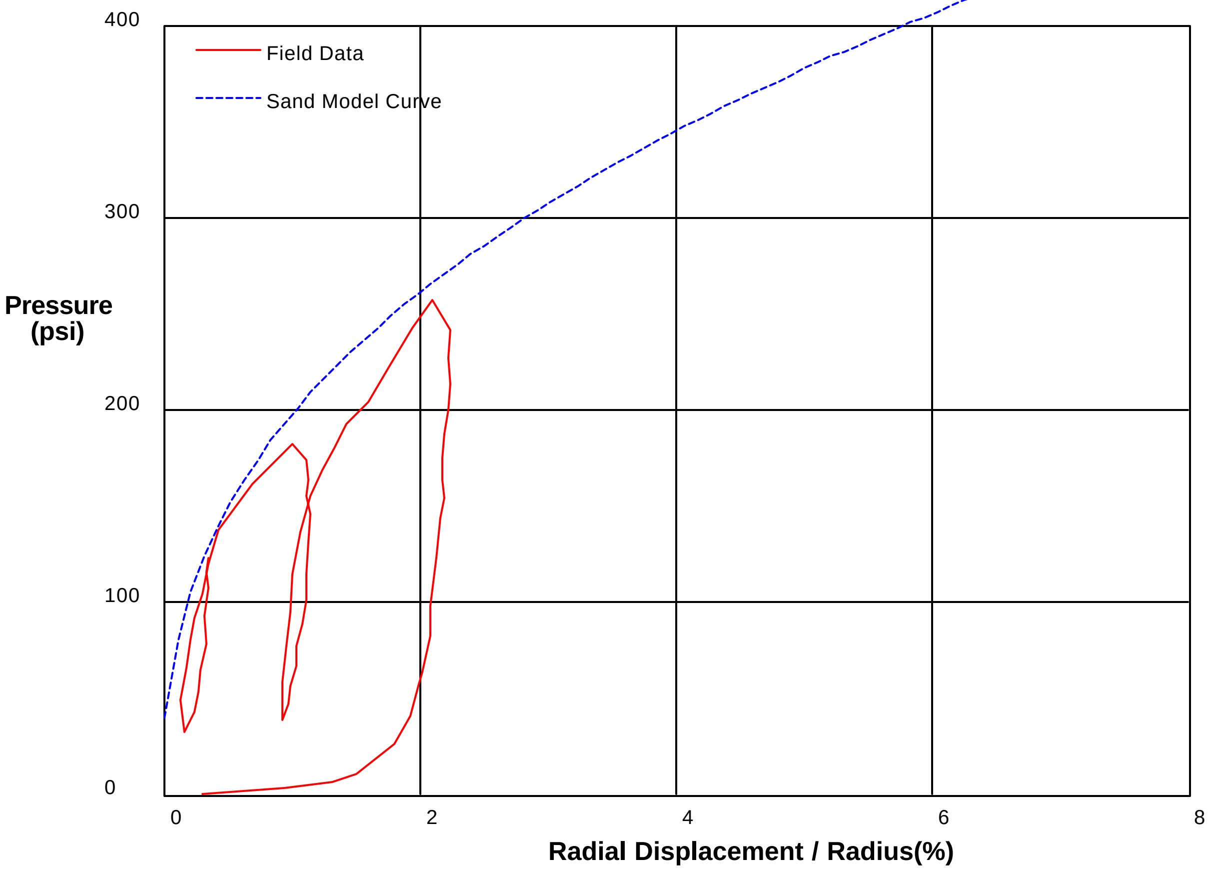
shift 6

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project Phase II **August 12, 2004**

Hole No. P44-02 **Depth 115 ft** **File C:\DATA\C-287\CDM3Z.P**



THE HUGHES SAND MODEL

Water Pressure	**46 psi**
Friction Angle	**36 deg**
Critical Friction Angle	**32 deg**
Lateral Stress	**40 psi**
Shear Modulus	**20000 psi**

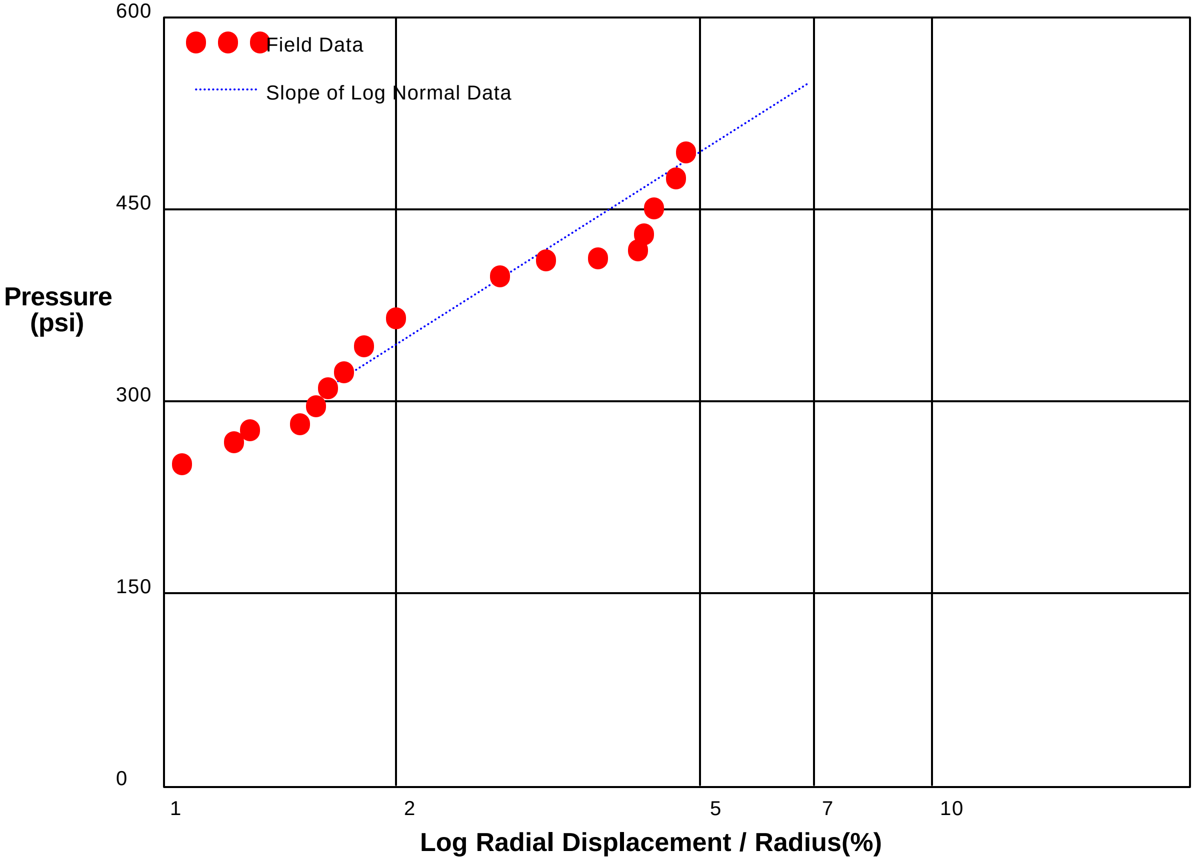
shift 13.5

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project Phase II **August 12, 2004**

Hole No. P44-02 **Depth 125 ft** **File C:\DATA\C-287\CDM5Z.P**



Shear Strength 164.6 psi
Limit Pressure 842 psi

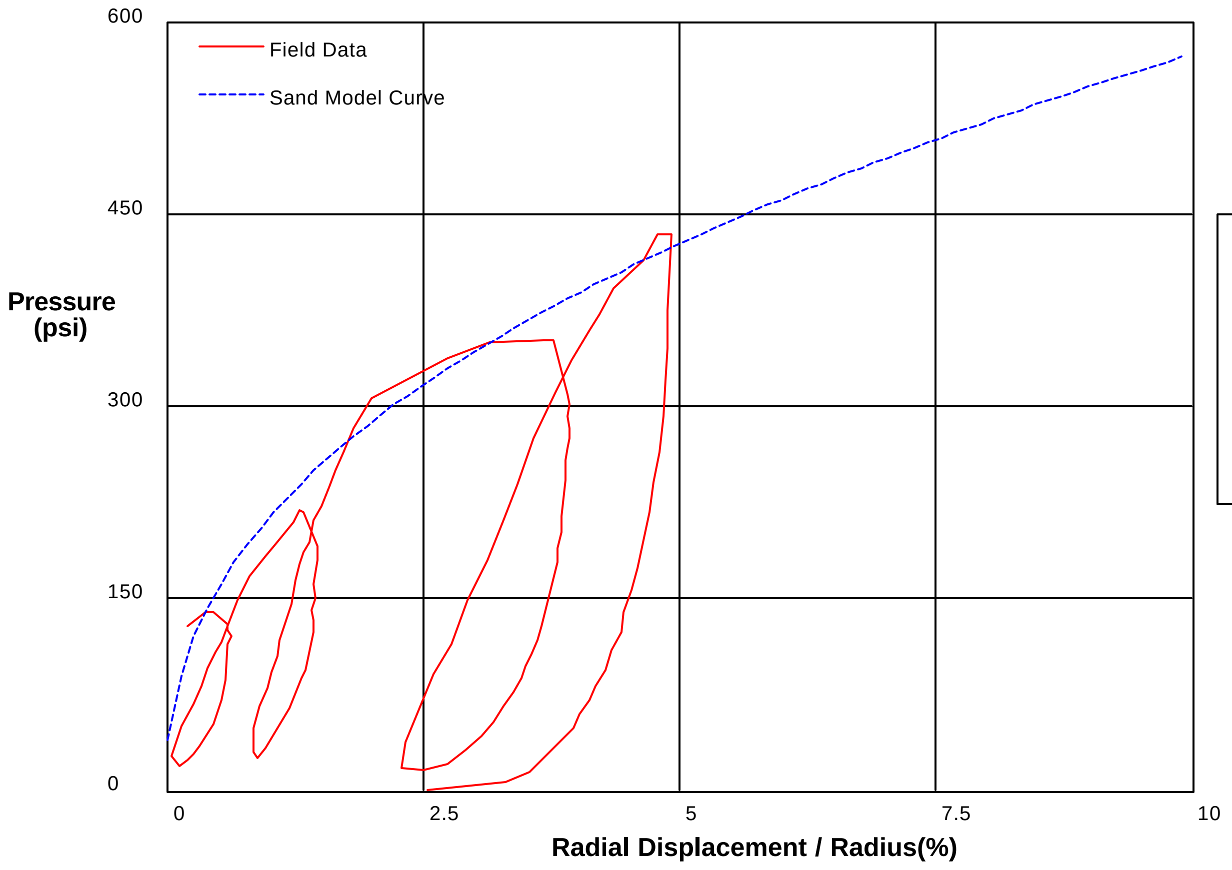
shift 5

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project Phase II **August 12, 2004**

Hole No. P44-02 **Depth 125 ft** **File C:\DATA\C-287\CDM5Z.P**



THE HUGHES SAND MODEL

Water Pressure	**60 psi**
Friction Angle	**38 deg**
Critical Friction Angle	**32 deg**
Lateral Stress	**40 psi**
Shear Modulus	**20000 psi**

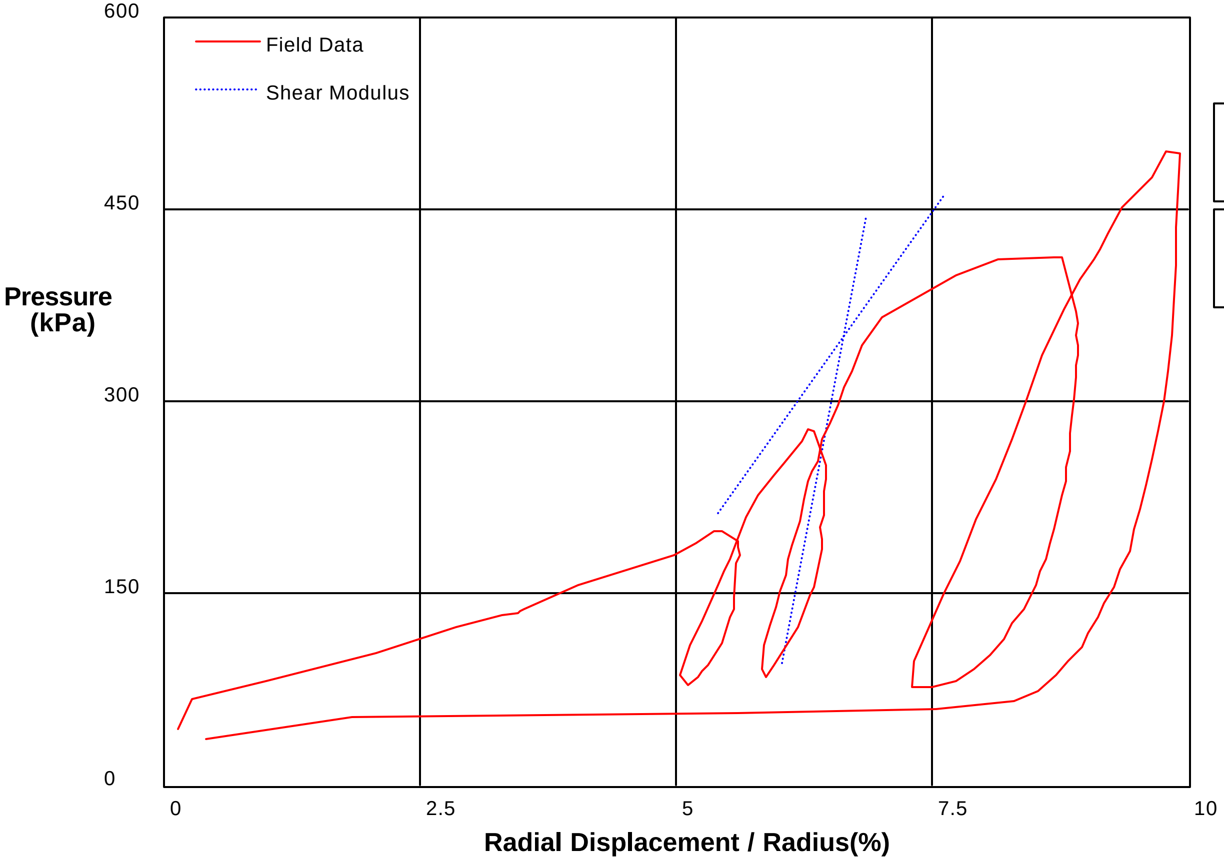
shift 5

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project Phase II **August 12, 2004**

Hole No. P44-02 **Depth 125 ft** **File C:\DATA\C-287\CDM5Z.P**



Shear Modulus 21548 kPa

Shear Modulus 5656 kPa

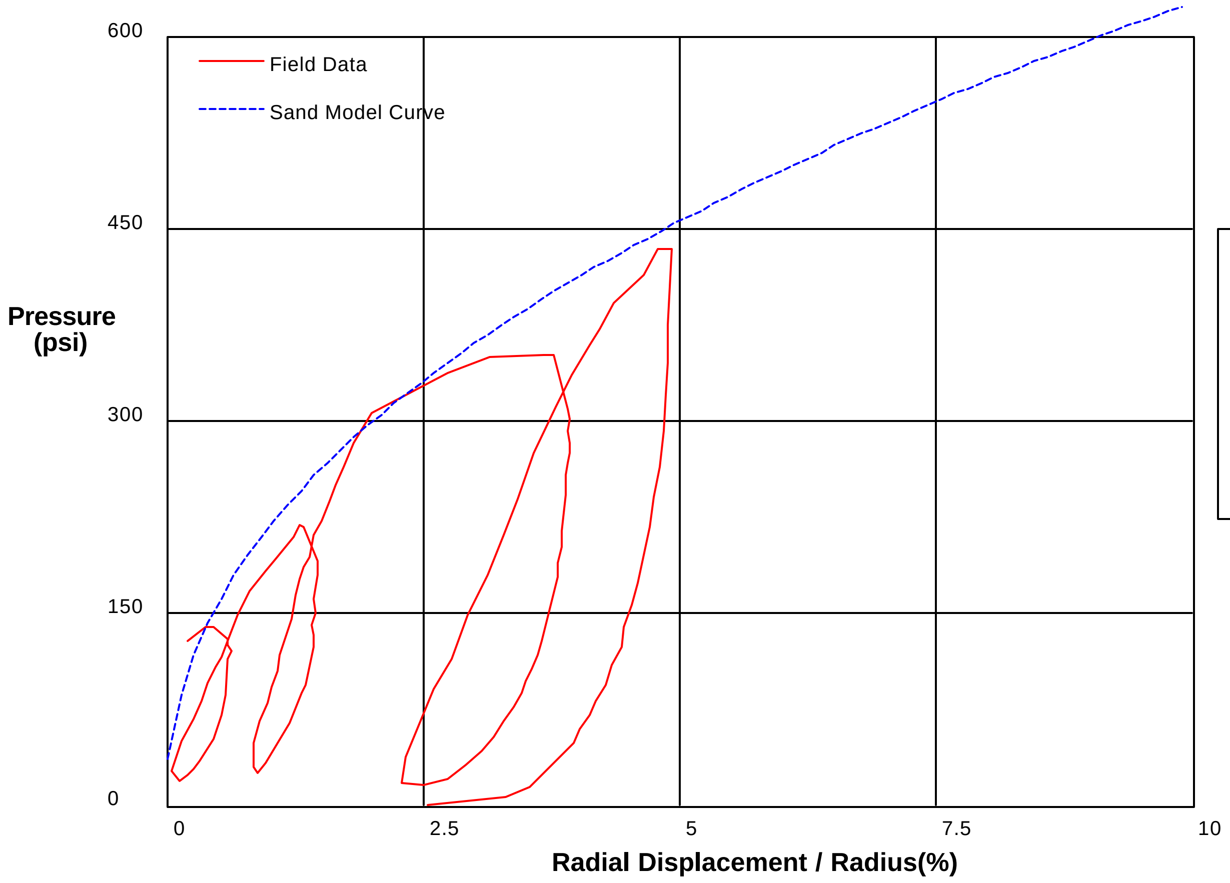
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project Phase II **August 12, 2004**

Hole No. P44-02 **Depth 125 ft** **File C:\DATA\C-287\CDM5Z.P**



THE HUGHES SAND MODEL

Water Pressure	**60 psi**
Friction Angle	**40 deg**
Critical Friction Angle	**32 deg**
Lateral Stress	**36 psi**
Shear Modulus	**20000 psi**

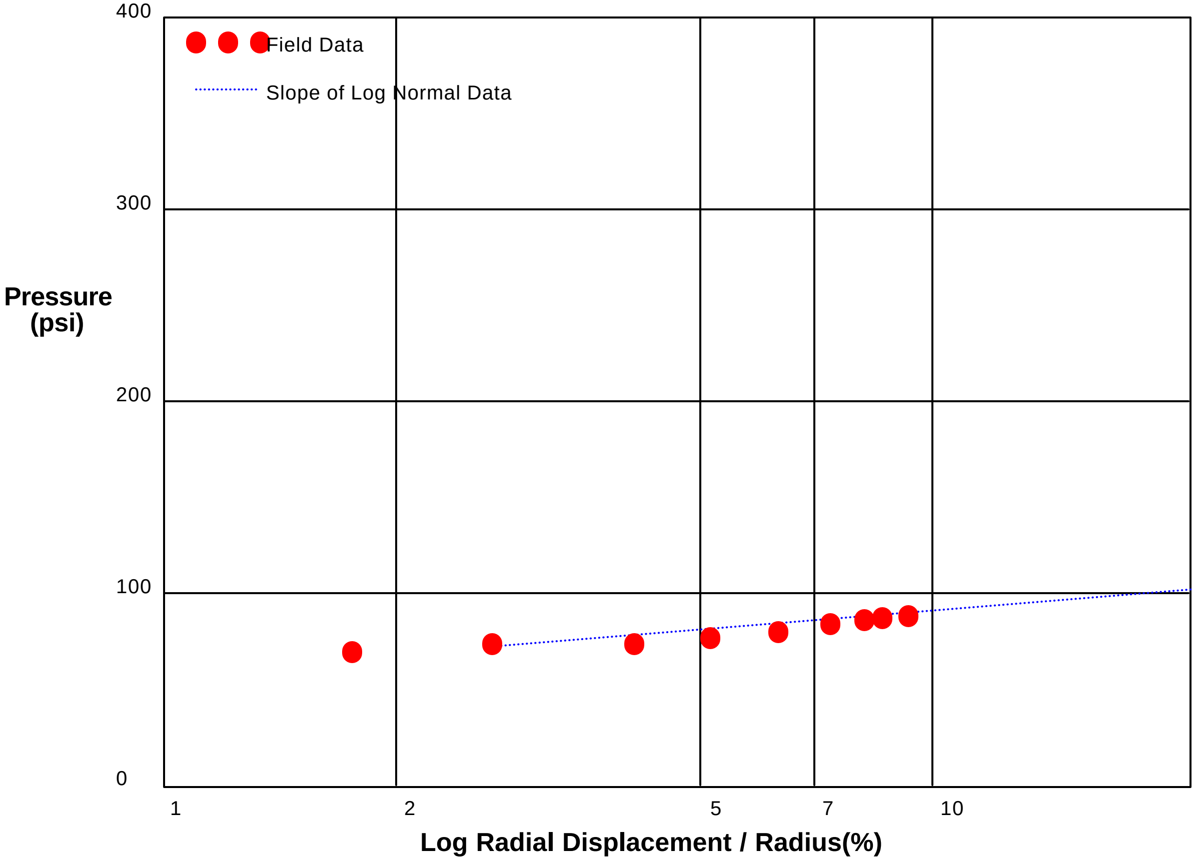
shift 5

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project Phase II **August 27, 2004**

Hole No. P42-02 **Depth 62.5 ft** **File C:\DATA\C-287\CDM7Z.P**



Shear Strength 14 psi
Limit Pressure 110 psi

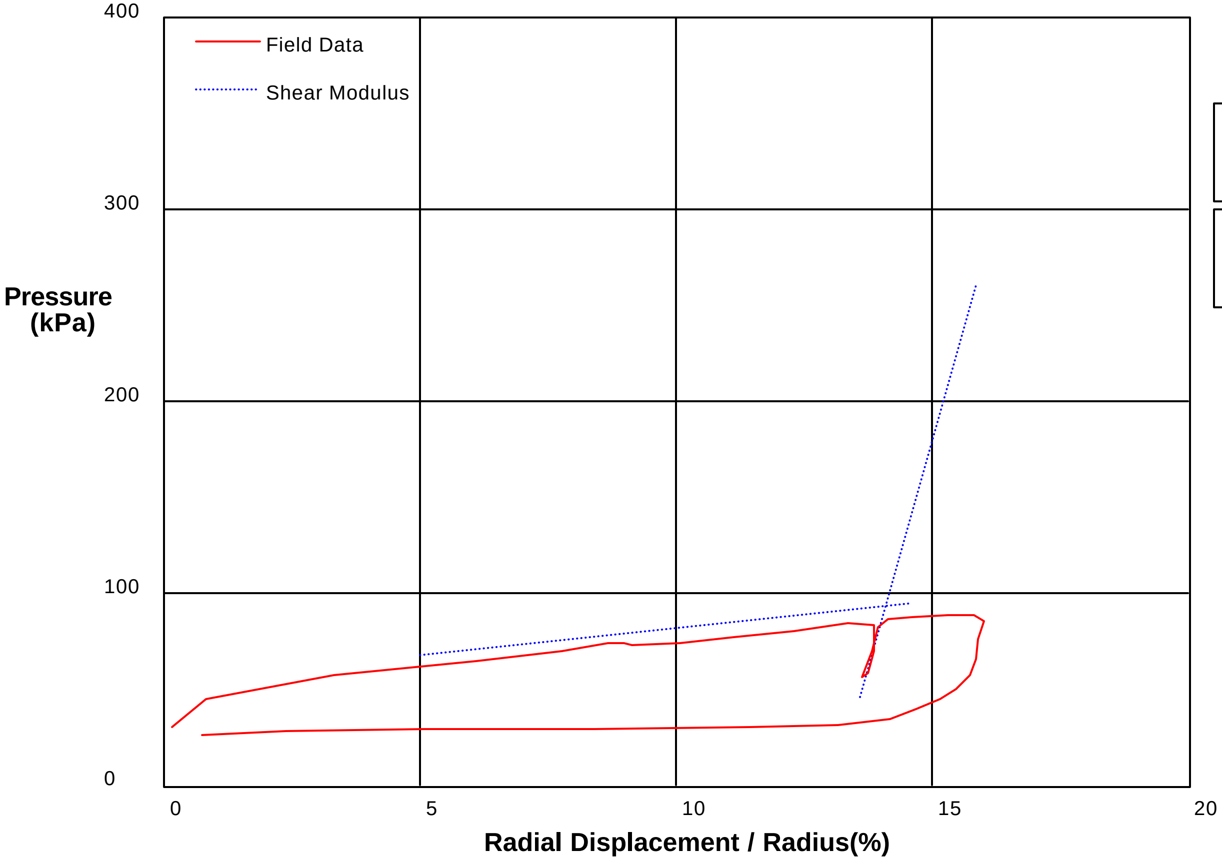
shift 6

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project Phase II **August 27, 2004**

Hole No. P42-02 **Depth 62.5 ft** **File C:\DATA\C-287\CDM7Z.P**



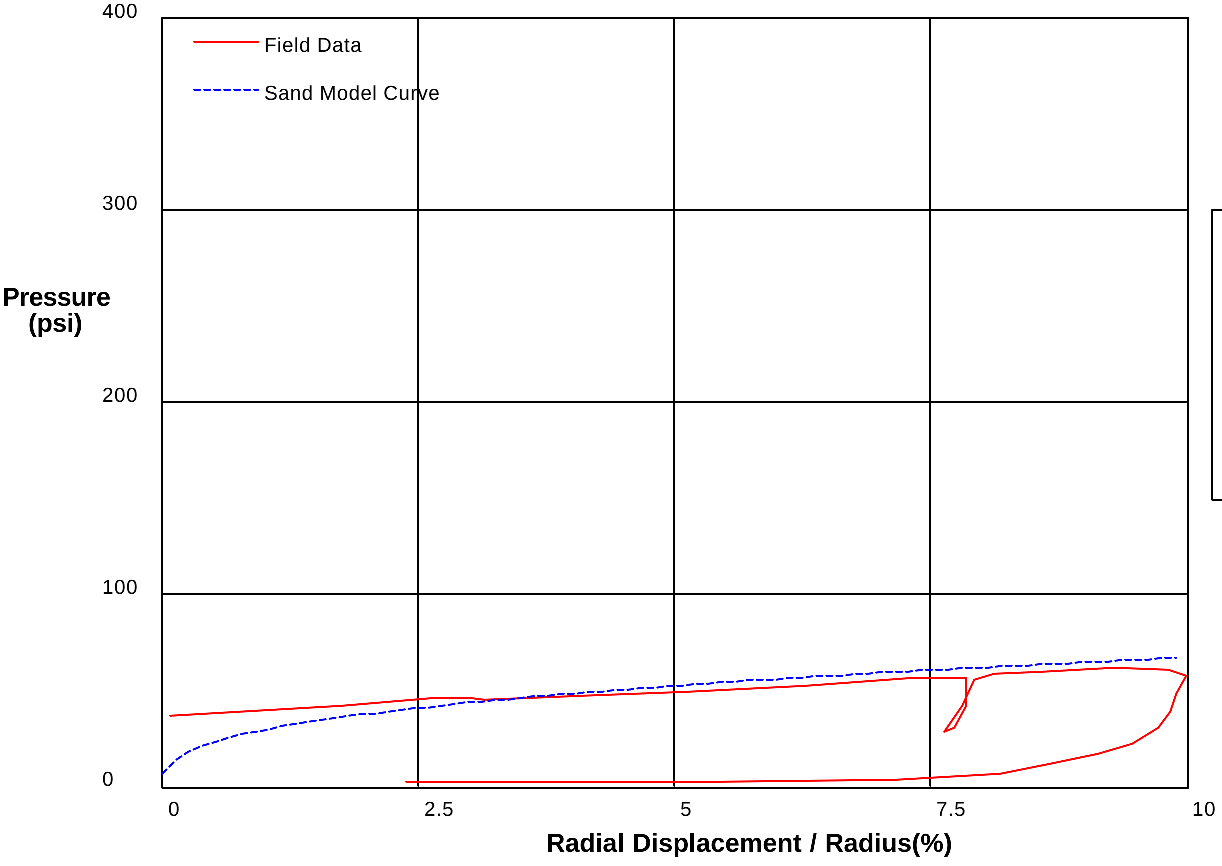
Shear Modulus 4735 kPa

Shear Modulus 140 kPa

shift 0

HUGHES

PRESSUREMETER DATA	**Camp Dresser & McKee Inc.**	
King County Brightwater Project Phase II		**August 27, 2004**
Hole No. P42-02	**Depth 62.5 ft**	**File C:\DATA\C-287\CDM7Z.P**



THE HUGHES SAND MODEL

Water Pressure	**28 psi**
Friction Angle	**33 deg**
Critical Friction Angle	**32 deg**
Lateral Stress	**6 psi**
Shear Modulus	**4000 psi**

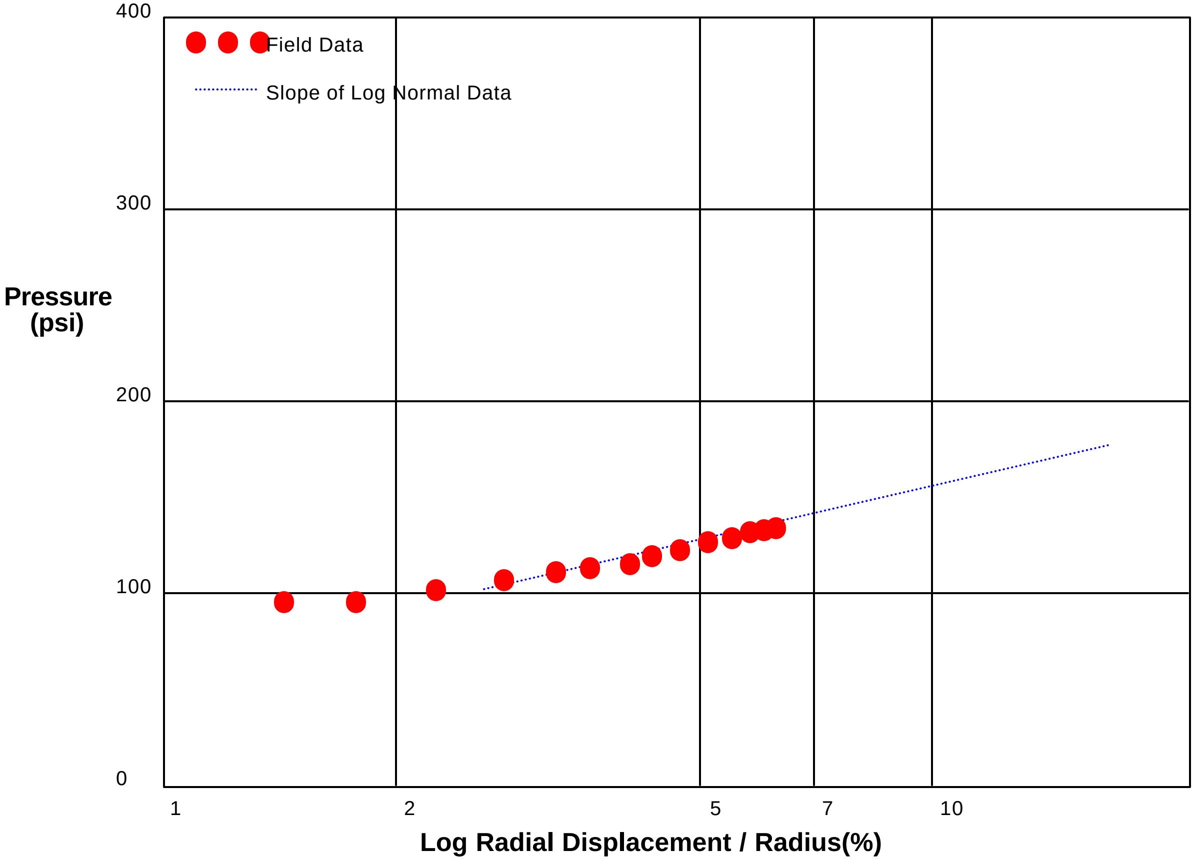
shift 6

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project Phase II **August 27, 2004**

Hole No. P41-02 **Depth 71.5 ft** **File C:\DATA\C-287\CDM8Z.P**



Shear Strength 40 psi
Limit Pressure 213 psi

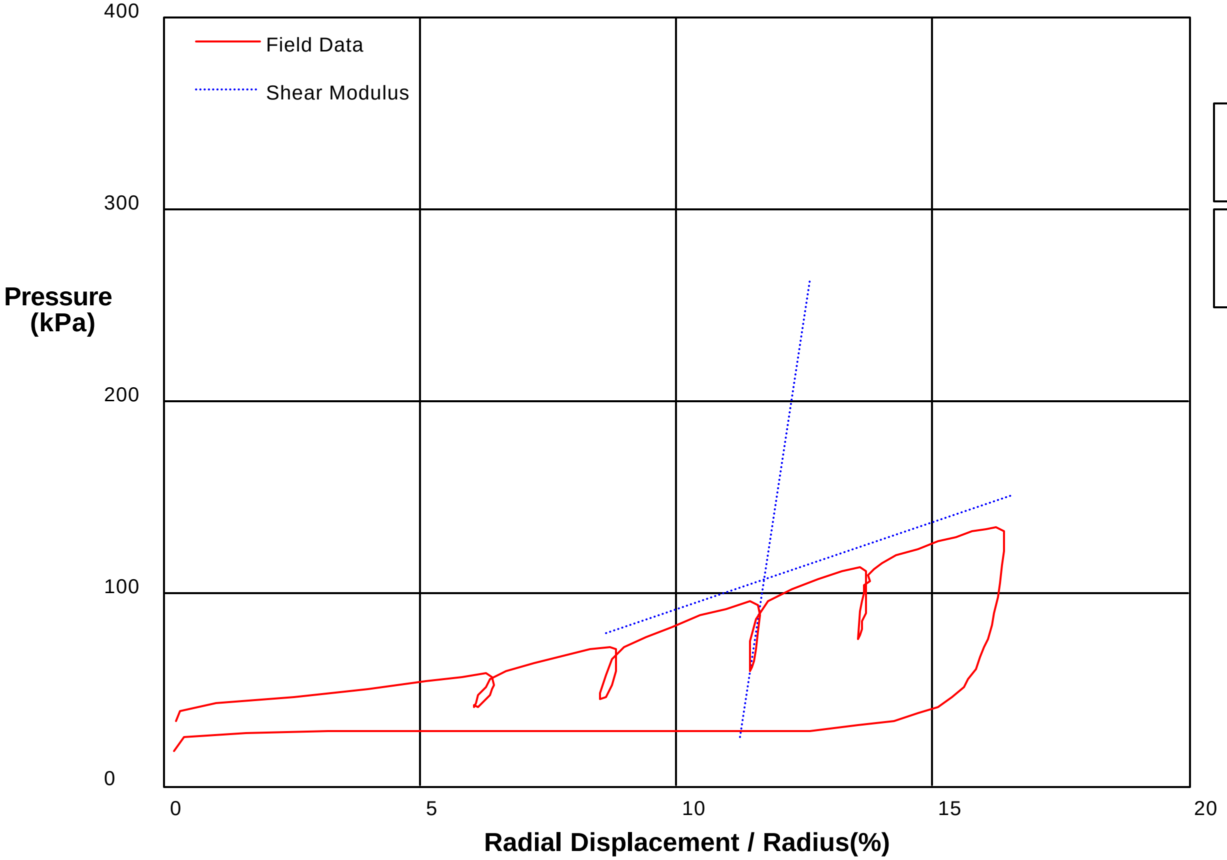
shift 10

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project Phase II **August 27, 2004**

Hole No. P41-02 **Depth 71.5 ft** **File C:\DATA\C-287\CDM8Z.P**



Shear Modulus 8820 kPa

Shear Modulus 456 kPa

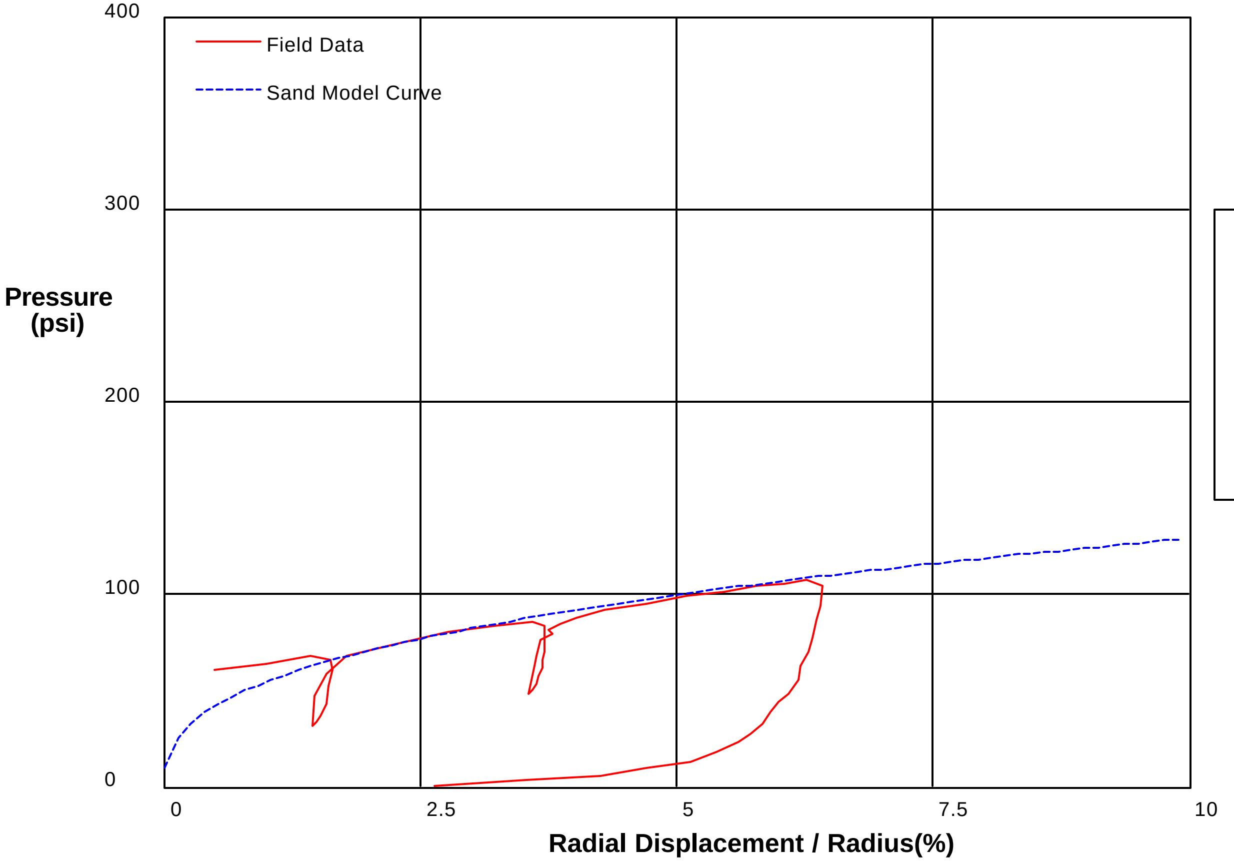
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project Phase II **August 27, 2004**

Hole No. P41-02 **Depth 71.5 ft** **File C:\DATA\C-287\CDM8Z.P**



THE HUGHES SAND MODEL

Water Pressure	**28 psi**
Friction Angle	**34 deg**
Critical Friction Angle	**32 deg**
Lateral Stress	**10 psi**
Shear Modulus	**8000 psi**

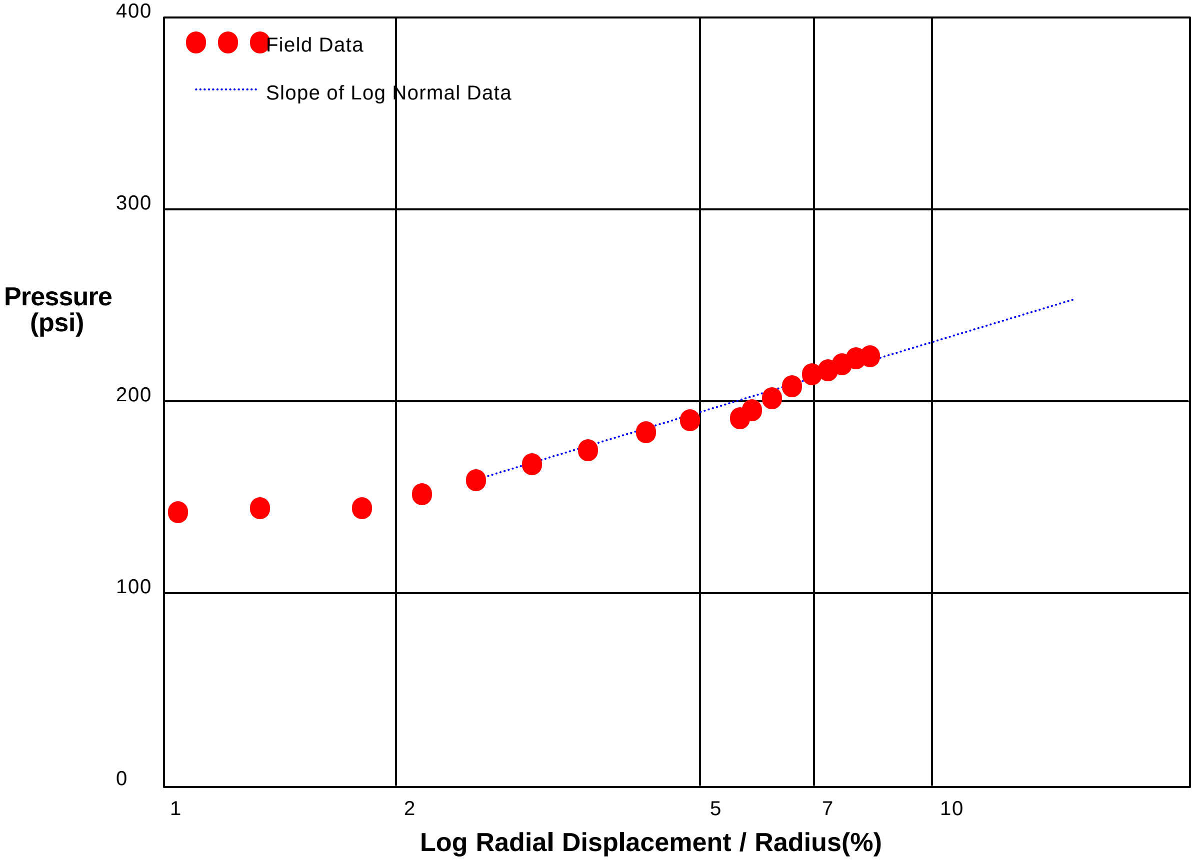
shift 10

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project Phase II **August 27, 2004**

Hole No. P41-02 **Depth 92.5 ft** **File C:\DATA\C-287\CDM9Z.P**



Shear Strength 52.1 psi
Limit Pressure 304 psi

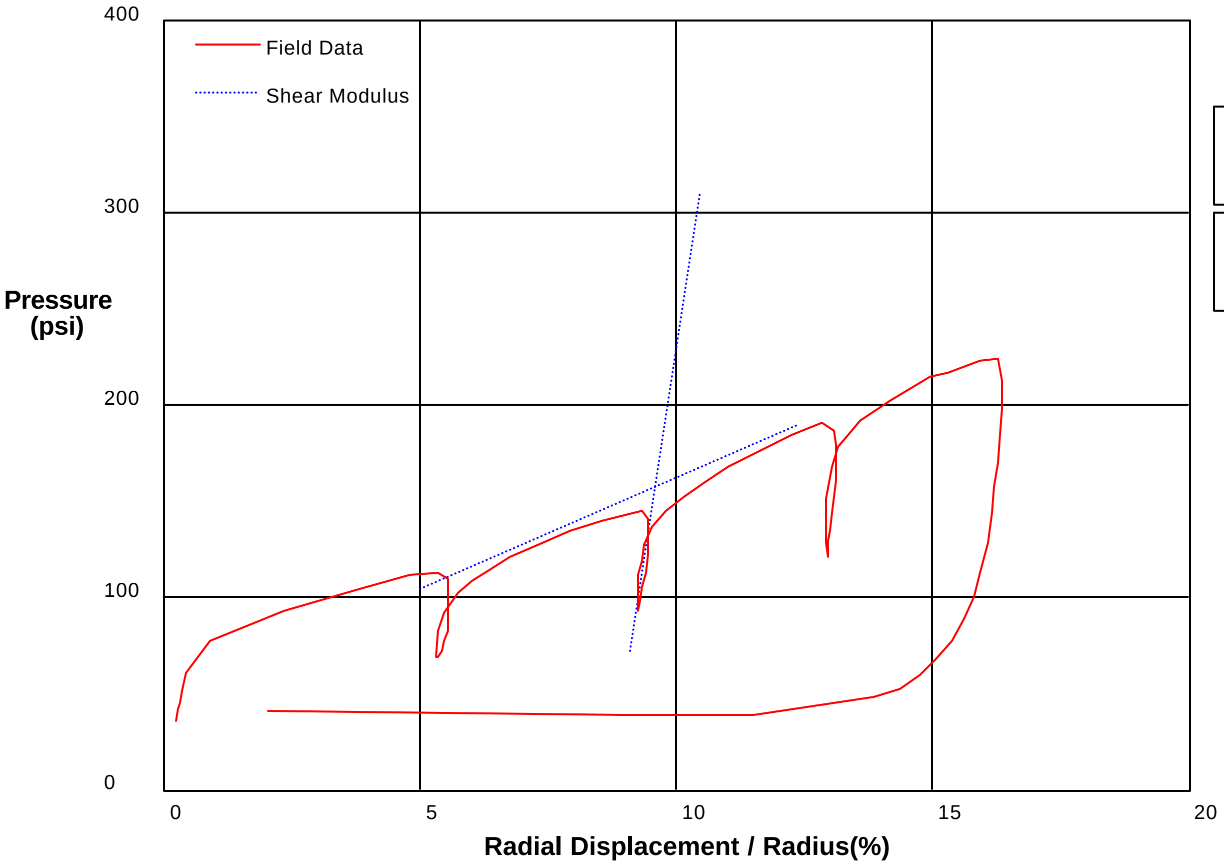
shift 8

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project Phase II **August 27, 2004**

Hole No. P41-02 **Depth 92.5 ft** **File C:\DATA\C-287\CDM9Z.P**



Shear Modulus 8820 psi

Shear Modulus 582 psi

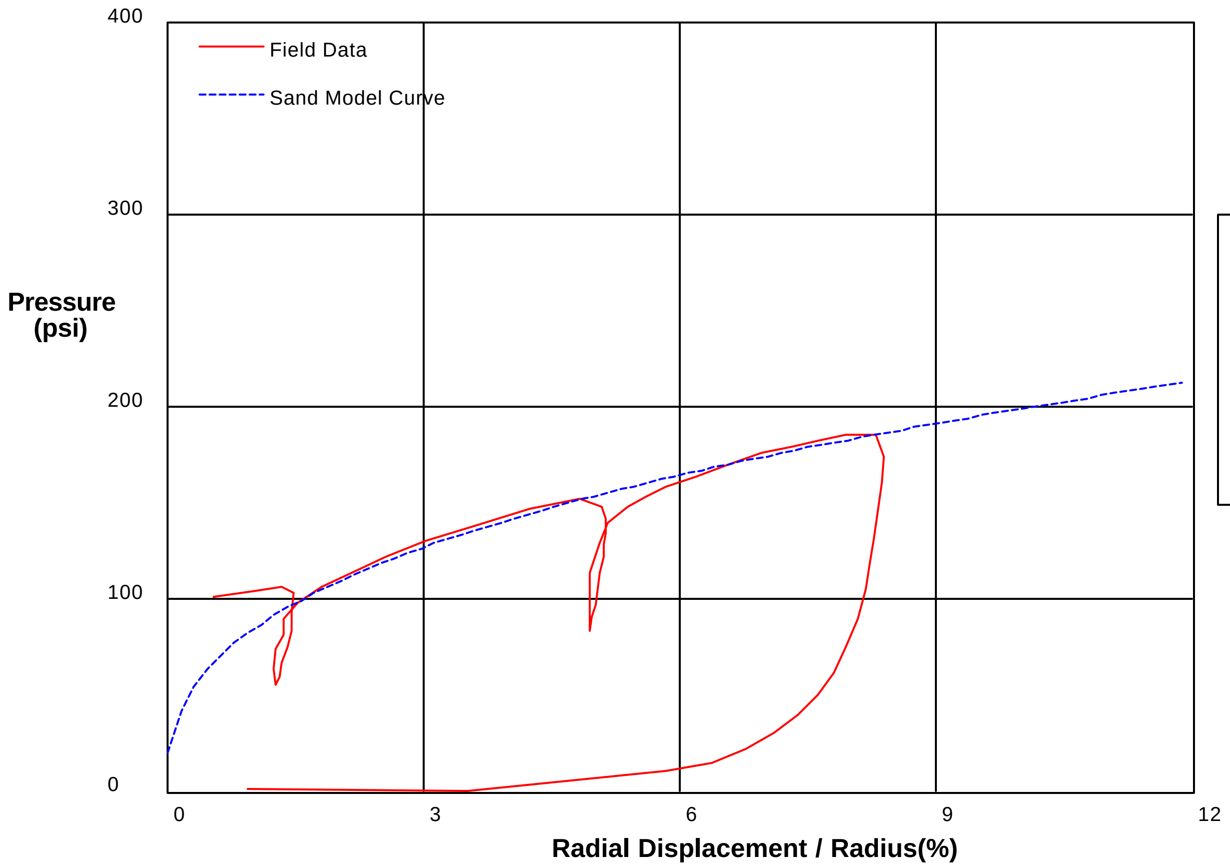
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee Inc.**

King County Brightwater Project Phase II **August 27, 2004**

Hole No. P41-02 **Depth 92.5 ft** **File C:\DATA\C-287\CDM9Z.P**



THE HUGHES SAND MODEL

Water Pressure	**38 psi**
Friction Angle	**34 deg**
Critical Friction Angle	**32 deg**
Lateral Stress	**20 psi**
Shear Modulus	**8000 psi**

shift 8

HUGHES

Pressuremeter Testing

King County Brightwater Project Phase II
Shaft Holes E-506 & P-502

submitted to

Camp Dresser & McKee Inc.

11811 N.E. 1st Street, Suite 20
Bellevue WA 98005

January 2005

C-287z

HUGHES INSITU ENGINEERING INC.
Suite 804, 938 Howe Street, Vancouver B.C. Canada V6Z-1N9
Phone (604) 331-4451 Fax (604) 331-4452

CONTENTS

TABLE

FIGURES

PHOTOGRAPHS

APPENDIX

Photograph 1

Lowering Pressuremeter from the Boart Longyear Vibrocore drill rig at location P502

1.0 INTRODUCTION

This report outlines the results of a pressuremeter study, conducted November 4 in Hole P-506, and November 12, 15 and 16 in Hole P-202, at the proposed shaft locations for the Brightwater Tunnels. Hole P-506 was drilled by Gregory Drilling Inc. Hole P-502 was drilled by Boart Longyear Inc. Hughes Insitu Engineering Inc. performed the pressuremeter testing under the direction of Mr. D. Yonomitsu, the CDM Field representative.

2.0 OBJECT OF THE PRESSUREMETER INVESTIGATION

The object of this investigation was to determine the *in-situ* stiffness and strength of the dense material at these locations.

3.0 PRESSUREMETER

The pressuremeter used for this study is a monocell pressuremeter. At the center of the pressuremeter are three electronic displacement sensors, spaced 120 degrees apart. Over these sensors is the flexible membrane, clamped at each end, which is pressurized to deform the adjacent material. A protective sheet of stainless steel strips covers the membrane. The pressuremeter was expanded by regulating the flow of gas from a bottle of compressed nitrogen. The electronic signals from displacement sensors and the pressure sensor are transmitted by cable to the surface. During the test, the average expansion against pressure curve is displayed on a computer screen.

The essential details of the instrument are shown in Fig. 1 and in Photograph 1.

4.0 HOLE FORMATION

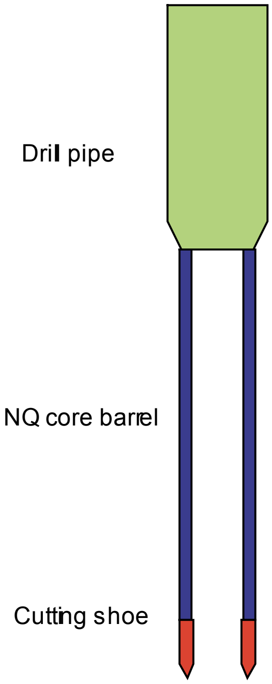
Hole P-506

A six-inch diameter uncased mudded-hole was advanced to the test level. At these locations the materials were predominantly granular, with few fine materials. The five-foot long pilot hole for the pressuremeter was cut with a $2^{15}/16$-inch diameter tricone bit. In view of the limited fines, the pilot hole was partially filled with slough by the time the pressuremeter was lowered into the hole. At each pilot hole location there was only sufficient hole to complete one pressuremeter test. As the outer protective shield was extensively damaged after each test, gravel was present at the test locations.

Hole P-502

The materials in the upper section of this hole were dense granular materials with little silt content. As the depth increased, the silt content in the gravel increased. At this location a vibrocore rig was used to cut the hole. Conventionally this system is used to drive a sample tube to obtain a disturbed sample for identification purposes. The advantage of the system is that an almost continuous core can be collected at a significantly fasters rate than with conventional mud rotary drilling. The vibrocore system can advance the hole very rapidly. However, the outer diameter of the hole cut by the sample tube is approximately six inches in diameter, far too large for the pressuremeter. To cut a three-inch diameter hole required for the pressuremeter, a special drive sampler was made. This sampler consisted of a five-foot section of N-size core barrel fitted with a heavy cutting shoe (shown in the sketch to the left of Photograph 2). This core barrel was attached to the main drill rods and vibrated into the ground. Below the water table in the upper dense granular material which had no silt binder, the method was not successful in forming a suitable hole. The granular material collapsed into the hole as soon as the sample tube was withdrawn. However, at lower levels where the silt content increased, the method was very successful in forming a hole of a suitable size for the pressuremeter.

The method of forming the hole may in itself cause some disturbance to the material surrounding the pressuremeter. This would result from the vibration and from the shape of the cutting shoe. The ideal cutting shoe requires a bevel on the cutting edge to be tapered inwards to limit the material being forced outwards during the penetration. The shoe as supplied had a bevel tapered both ways. However, in sands, as the modulus obtained from instruments forced into the ground and carefully self-bored into the sand are very similar, the above method of insertion should give a reasonable measure of the *in-situ* modulus.



Photograph 2

Three-inch diameter cutting shoe used to form pilot hole for the pressuremeter
(Note taper inwards and outwards on shoe)

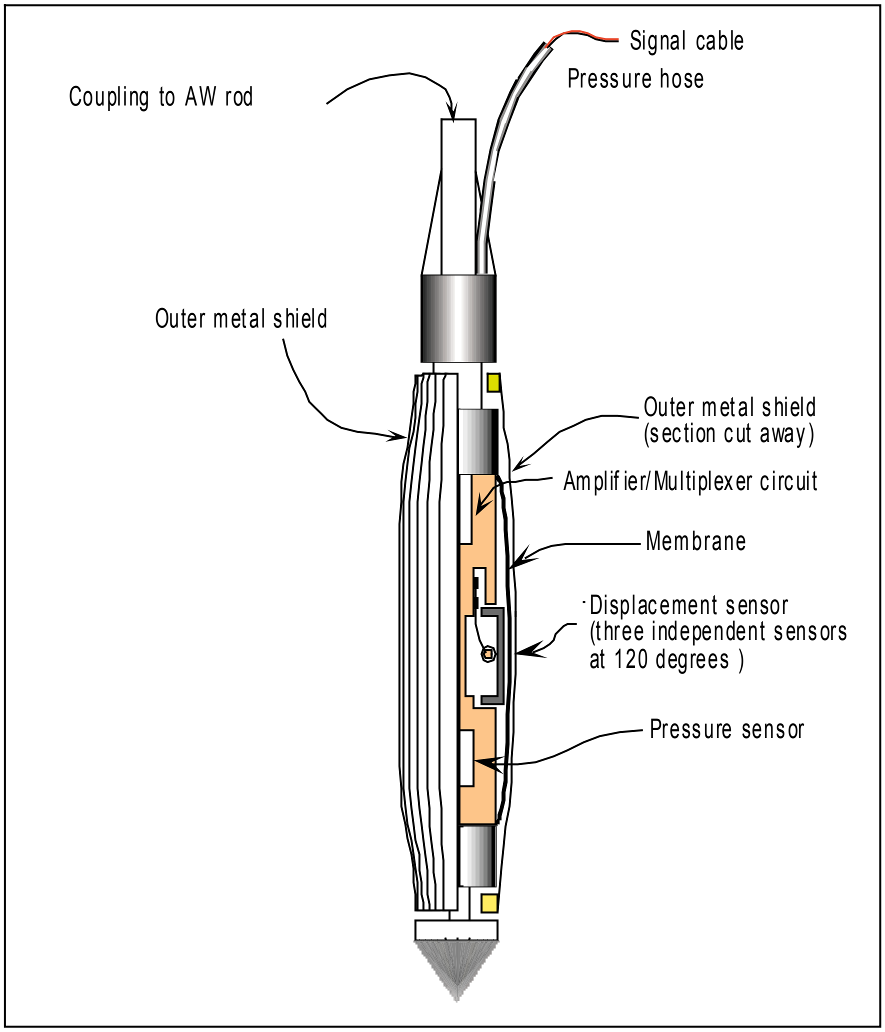


Fig. 1. Schematic outline of pressuremeter

5.0 TEST PROCEDURE

After the pressuremeter was inserted to the bottom of the hole, the membrane was expanded by controlling the flow of compressed nitrogen into the pressuremeter, increasing the pressure in small steps. The pressure was increased until one of the strain sensors reached a limit.

During this expansion several unload-reload loops were conducted to determine the low strain shear modulus. Prior to each unload cycle, the pressure was held constant for four minutes to obtain a qualitative indication of the creep behavior of the matrix.

If the material surrounding the pressuremeter is assumed to extend to infinity, and to behave in an idealized manner, as a linear elastic, homogeneous material, which does not fail under shear or tension, then the displacement on the boundary of the pressuremeter, $u_{\forall}$, for a given pressure, P, is given by:

$$U_{\mathrm{a}} = \mathrm{P.a}\ (1+\mu)\ /\ E \qquad 1)$$

where E is the Young's Modulus, a the radius of the pressuremeter cavity, and μ the Poisson's ratio.

As the shear modulus, G, and the Young's modulus, E, are related by the following relationship:

$$E=2.G.(1+\mu) \qquad 2)$$

Equation 1 reduces to:

$$U_{\mathrm{a}} = 0.5P.\mathrm{a}\ /\ G \qquad 3)$$

Hence, the shear modulus G is given by:

$$\mathrm{G} = 0.5)(\text{Pressure})/)(\text{radial displacement/radius}) \qquad 4)$$

The pressuremeter data is often characterized by the modulus determined from the initial slope of the pressuremeter curve. In many instances this is not clearly defined, as the pressuremeter curve does not always show a distinct linear section near the start. Hence, the choice of the initial modulus is subjective. The shear modulus values for the average slope of the initial part of the pressuremeter curve of all of the tests are summarized in Table 1. The modulus for the average slope of the pressuremeter curve expressed as a Young's modulus (assuming a Poisson's ratio of 0.33) is the same as the "pressuremeter modulus" defined in the American Society for Testing and Materials (ASTM D4719-94, Section 9.5). Also included in Table 1 is the modulus determined from any unload-reload loops. This modulus is much more clearly defined and can be used to give an indication of the true elastic properties of the material.

6.0 STANDARD PRESSUREMETER PARAMETERS

Limit pressure and shear strength

As a quantitative measure of the strength of the material, the “limit pressure”, P_L, is commonly used. This is the pressure, which is calculated to occur when the pressuremeter has been assumed to deform the material by doubling the initial volume of the cavity. If the material being tested is assumed to behave as an elastic cohesive material, then the equation governing the pressure-displacement curve is given by:

$$P = P_L + c.\log_e (u_a/a) \qquad 5)$$

where P_L is the theoretical limit pressure at infinite expansion.

$$P_L = P_o + c + c.\log_e [G/c] \qquad 6)$$

Here, c is the undrained cohesive strength, P_O is the total *in-situ* lateral stress, and G the shear modulus. For typical values of G and c the ratio G/c lies between 50-100. Hence, the limit pressure is approximately 5 times the shear strength (assuming P_o is small relative to c).

From Equation 5, a plot of pressure P against the log of u_a/a will be a straight line, provided the shear strength remains constant with strain. The slope of this line will give a measure of the shear strength c. The limit pressure, as defined by the ASTM code D4719, Section 9.6, is the pressure at which the cavity has doubled in size. This doubling in size occurs when u_a/a is equal to 41%. (The origin of the strain used in the log/normal plots is the assumed origin at the *in-situ* stress state).

The shear strengths calculated by this method for Seattle materials are usually an overestimate of the *in-situ* shear strength. Therefore, they have not been reported in Table 1.

7.0 MODEL METHOD OF ANALYSIS

As an alternative method of analysis, an ideal pressuremeter curve can be developed, based on fundamental material parameters. This ideal curve can then be compared to the field data. Adjustments can then be made to the model parameters, such that the ideal pressuremeter curve and the model curve match. The ideal pressuremeter curve is a function of the assumed material model. If the material is assumed to behave as a cohesive material, the required parameters are the cohesive strength, initial secant modulus and the total *in-situ* stress. If the material behaves in a predominantly frictional manner, the friction angle, rather than cohesion, is a necessary parameter. In the cohesive materials the final unloading can be analyzed to give another indication of the shear strength. The shear strength determined from the unloading curve will, in an ideal homogeneous material, be twice the undrained shear strength. This occurs because the unloading curve represents material that is initially failing, while moving outwards at the end on the initial loading phase of the test, the direction of failure reverses on unloading as the material moved inwards on the body of the pressuremeter. If the material behaves the same in both directions, then the shear strength determined from the unloading curve will be twice the loading shear strength.

8.0 REFERENCES

Mair, R.J., and Wood, D.M. 1987. Pressuremeter testing: methods and interpretation. CIRIA Ground Engineering Report. Butterworths, London.

ASTM D4719. 1994. Standard test method for pressuremeter testing in soils.

Table 1. Basic material properties from pressuremeter tests

File Number	Hole	Depth (feet)	Initial shear modulus (psi)	Unload-reload Shear modulus (psi)	Limit Pressure (psi)	Cohesion (psi)[2]	Friction angle[3]
BWTR1	E-506	111	32,000	6,000	>1,000	-	40
BWTR2	E-506	125	28,000	4,000	1,000	170-?	-
BWS3	P-502	123.5	12,000	2,000	800	100- 80	-
BWS4	P-502	62.5	6,000	1,500	600	80- 65	-
BWS5	P-502	159.5	80,000	19,000	>1,000	-	38
BWS6	P-502	184	180,000	19,000	>2,000	-	40
BWS7	P-502	205	13,000	3,300	1,100	180-120	
BWS8	P-502	203	12,000	2,200	1,100	180- 120	

Notes

[1] The depths refer to the bottom of the test section. The whole test section is 16 inches in length.

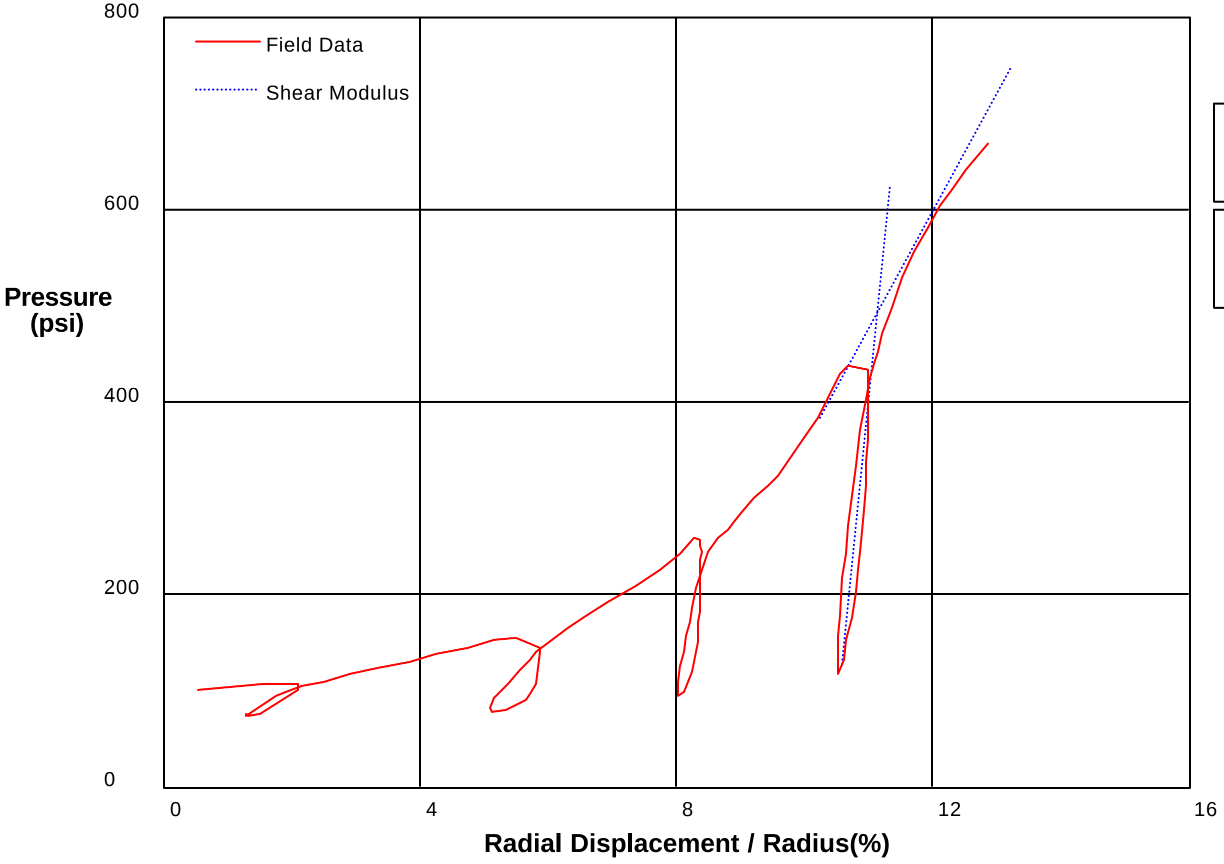
[2] In this column the cohesive values are the undrained cohesive strength assuming zero friction angle. The first value is from the loading section of the curve the second value is from the unloading section. In Test BWTR2 the strains were taken beyond the limit of the strain sensors. Hence the displacements on the membrane were not measured during most of the unloading phase.

[3] The friction values in the last column assume no cohesion. However it is likely that some cohesion does exist.

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Project Phase II **11-04-04**

Hole No. E-506 **Depth 111 feet** **File C:\DATA\C-287\BWTR1.P**



Shear Modulus 32342 psi

Shear Modulus 6111 psi

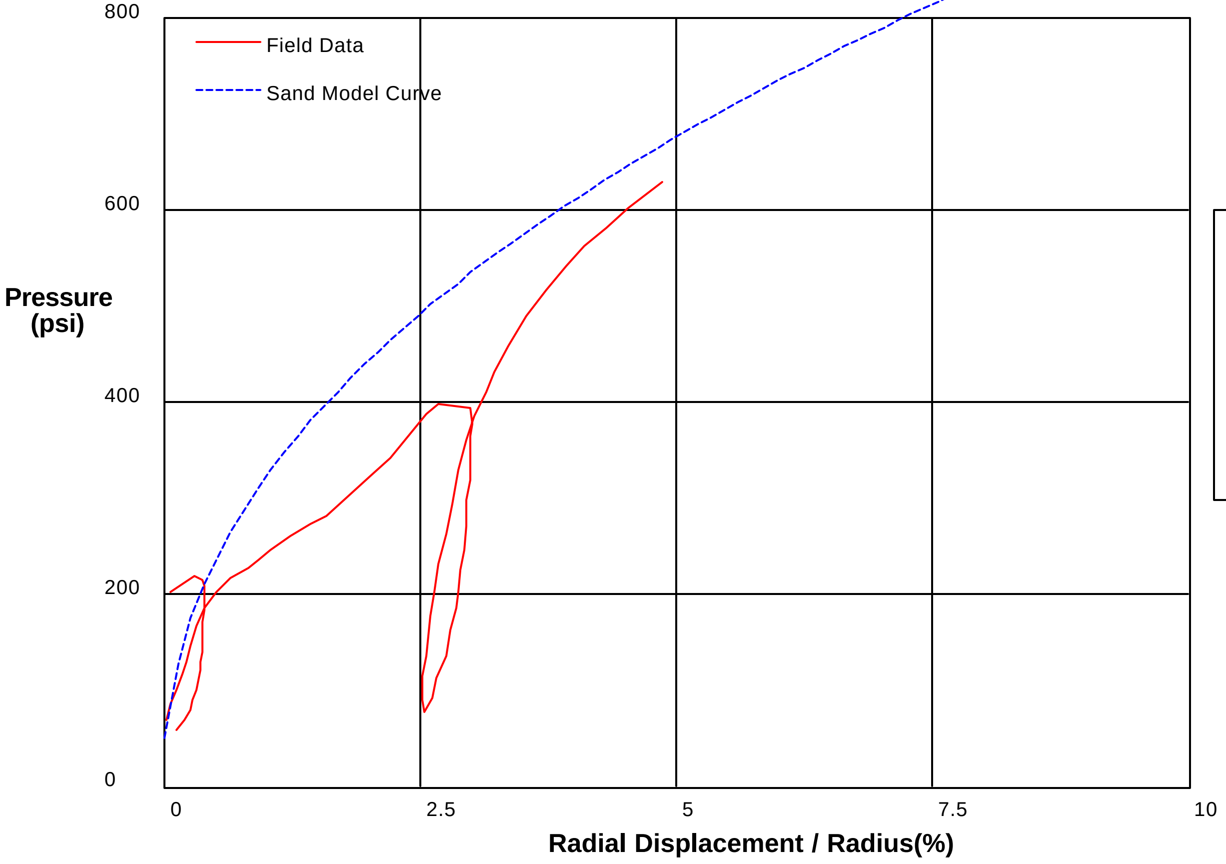
shift 10

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Project Phase II **11-04-04**

Hole No. E-506 **Depth 114 feet** **File C:\DATA\C-287\C-287\BWTR1.P**



THE HUGHES SAND MODEL

Water Pressure	**40 psi**
Friction Angle	**40 deg**
Critical Friction Angle	**32 deg**
Lateral Stress	**50 psi**
Shear Modulus	**32000 psi**

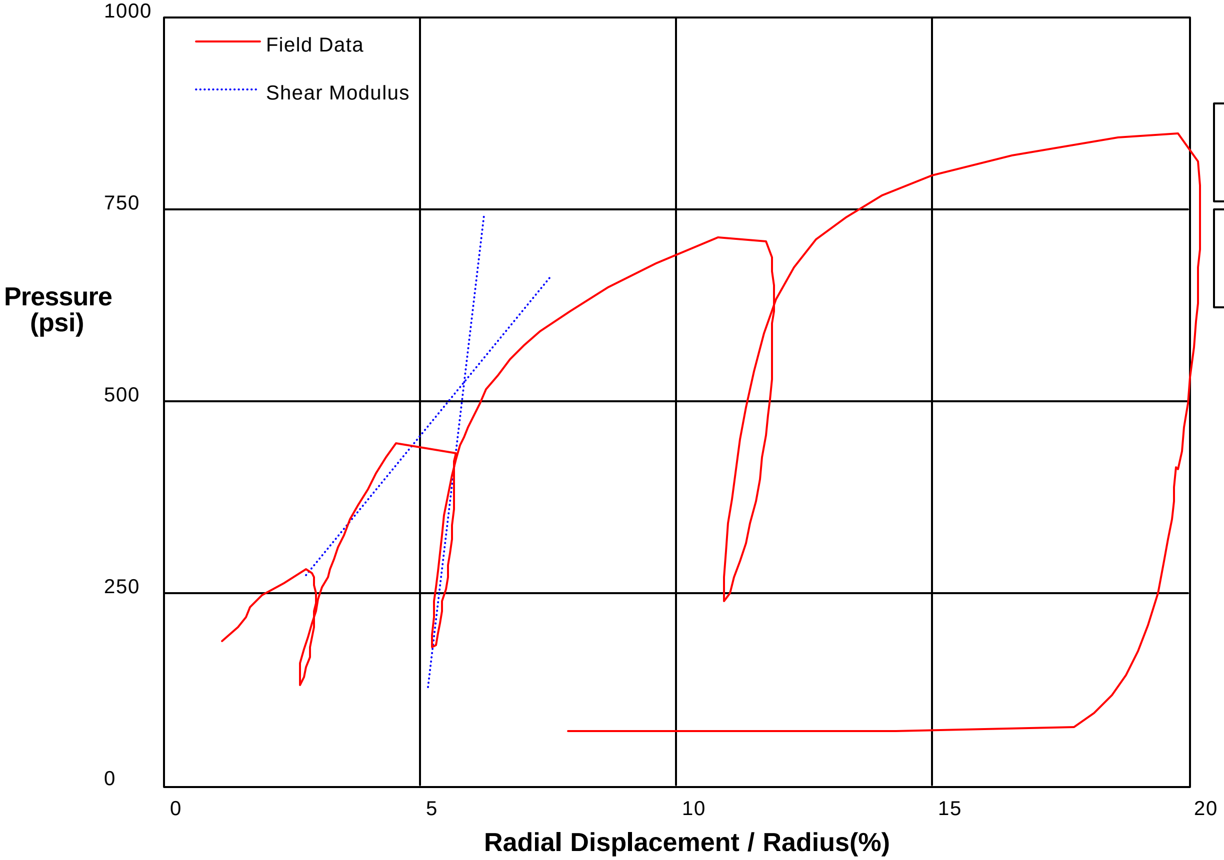
shift 18

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Project Phase II **11-4-04**

Hole No. E-506 **Depth 125 feet** **File C:\DATA\C-287\BWTR2.P**



Shear Modulus 28095 psi

Shear Modulus 4057 psi

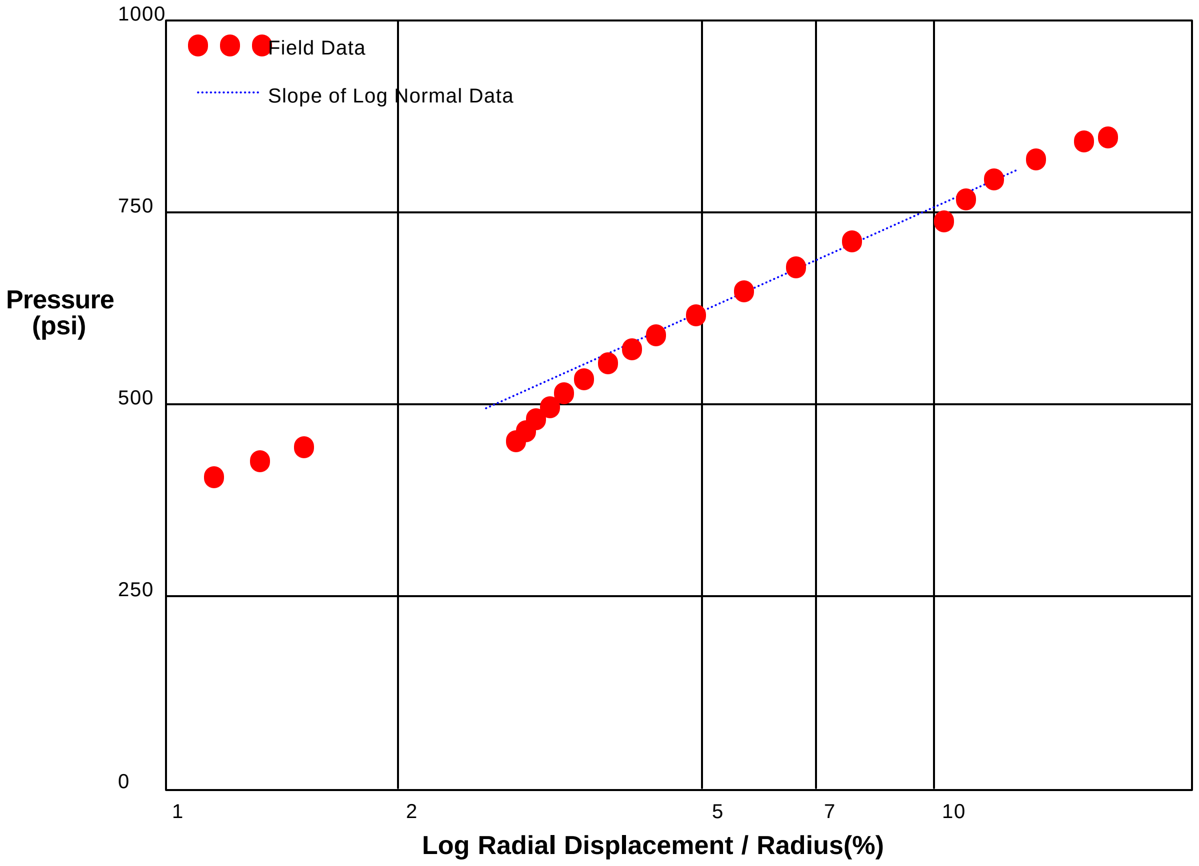
shift 4

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Project Phase II **11-4-04**

Hole No. E-506 **Depth 125 feet** **File C:\DATA\C-287\BWTR2.P**



Shear Strength 194.2 psi
Limit Pressure 1031 psi

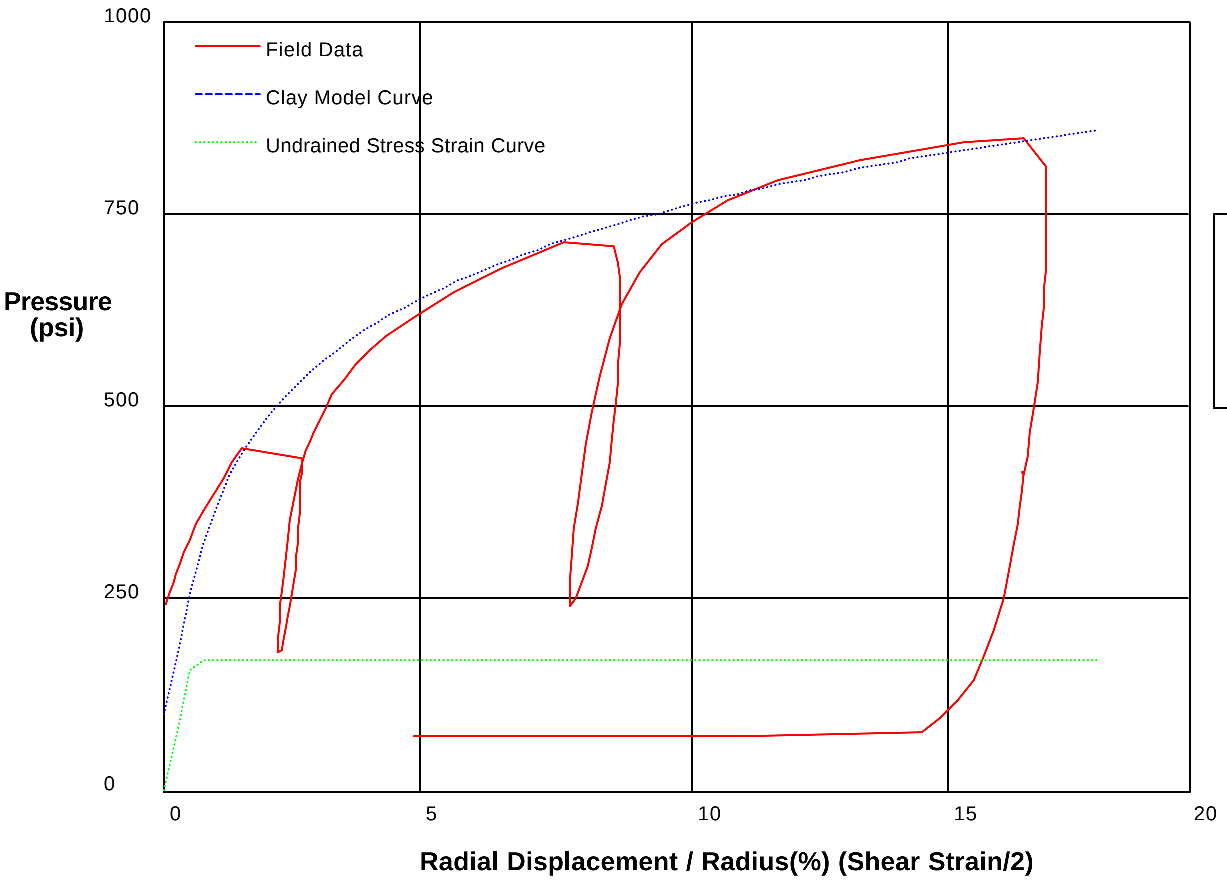
shift 7

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Project Phase II **11-4-04**

Hole No. E-506 **Depth 125 feet** **File C:\DATA\C-287\BWTR2.P**



GIBSON'S CLAY MODEL

Shear Strength	**170**	**psi**
Insitu Stress	**100**	**psi**
Shear Modulus	**15000**	**psi**

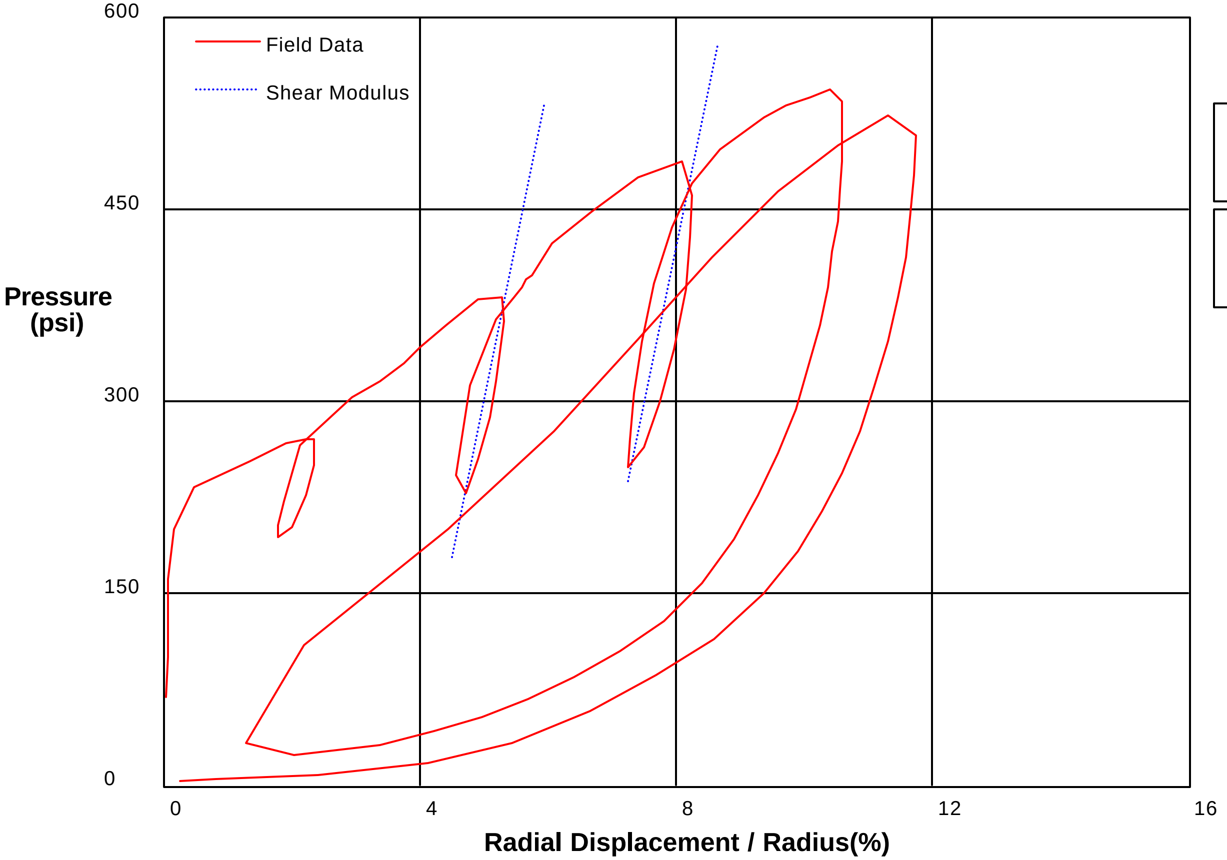
shift 7

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee, Inc.**

King County Brightwater Project Phase II **November 12, 2004**

Hole No. P5-02 **Depth 72 ft** **File C:\DATA\C-287\BWS3.P**



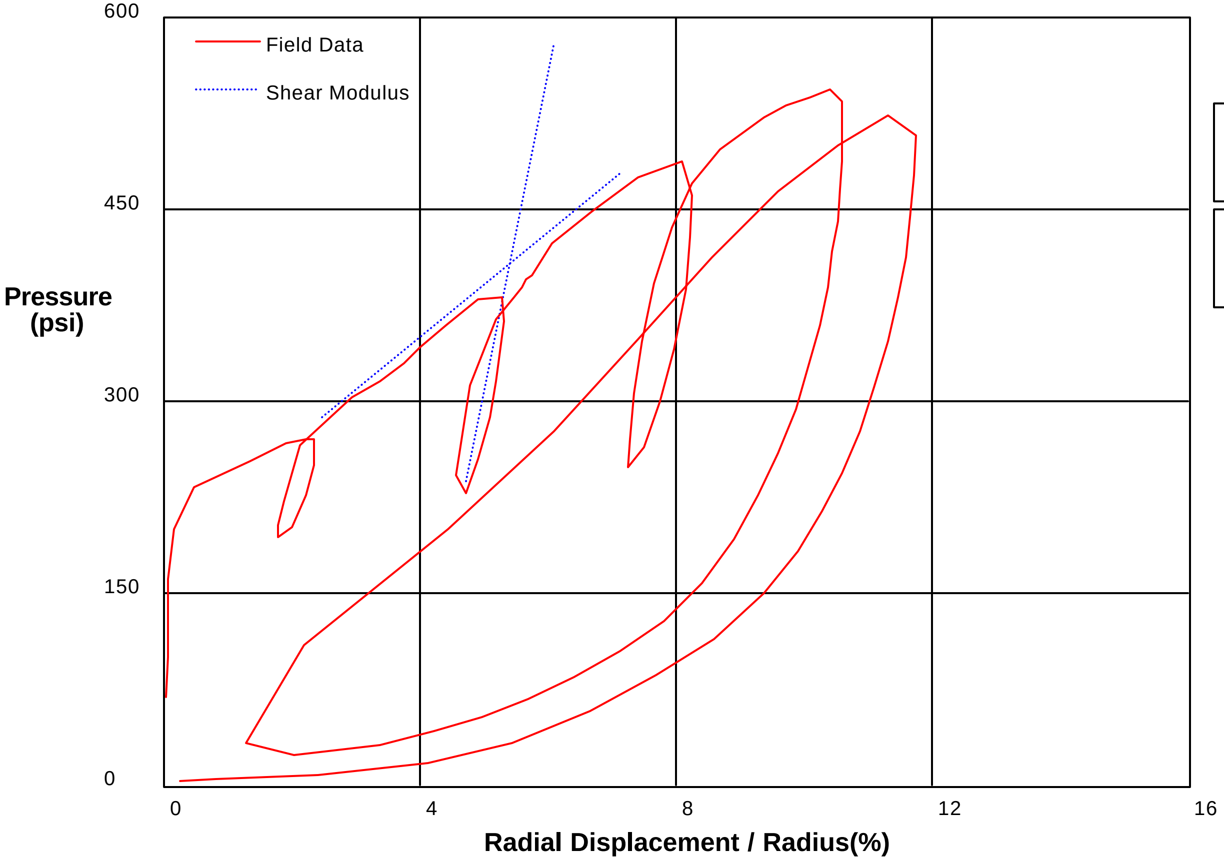
Shear Modulus 12276 psi

Shear Modulus 12282 psi

shift 0

HUGHES

PRESSUREMETER DATA	**Camp Dresser & Mckee Inc.**	
King County Brightwater Projecty Phase II		**November 12, 2004**
Hole No. P-502	**Depth 72 ft**	**File C:\DATA\C-287\C-287\BWS3.P**



Shear Modulus 12276 psi

Shear Modulus 2053 psi

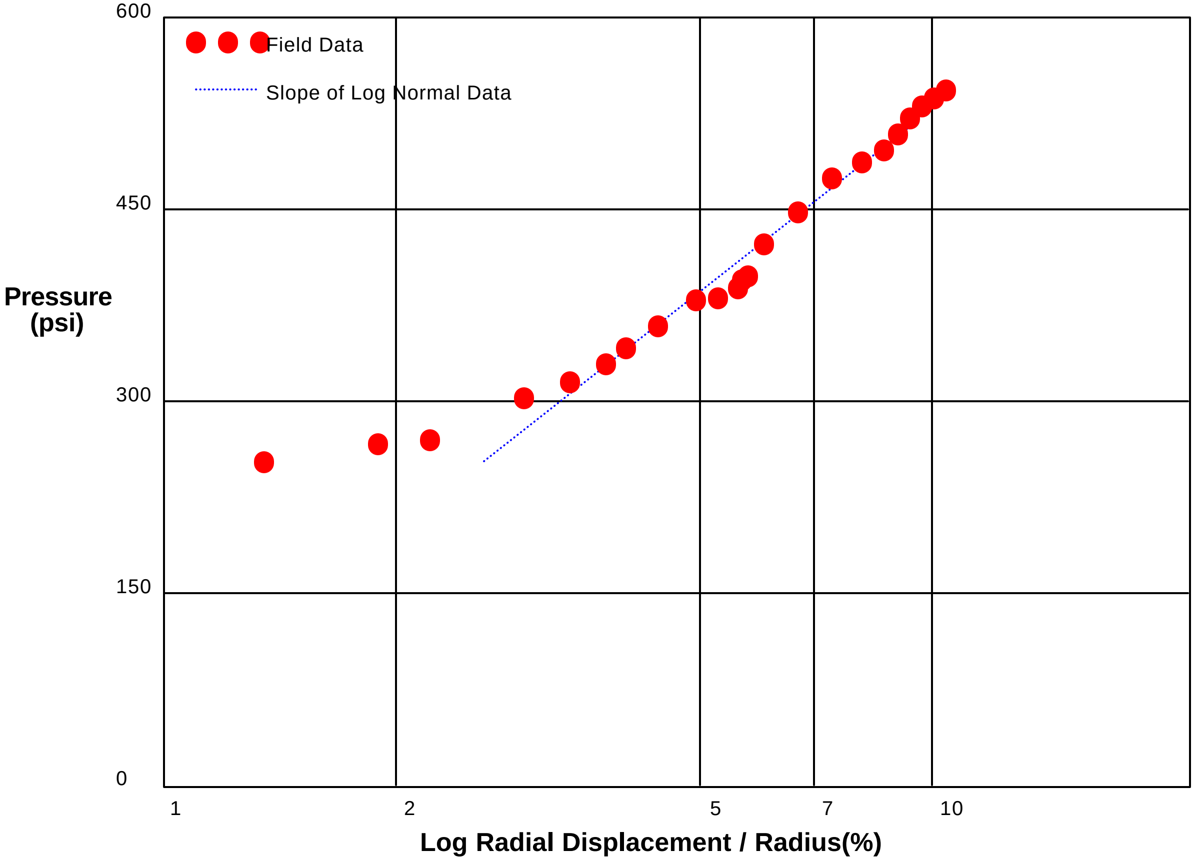
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Projecty Phase II **November 12, 2004**

Hole No. P-502 **Depth 72 ft** **File C:\DATA\C-287\C-287\BWS3.P**



Shear Strength 204.1 psi
Limit Pressure 816 psi

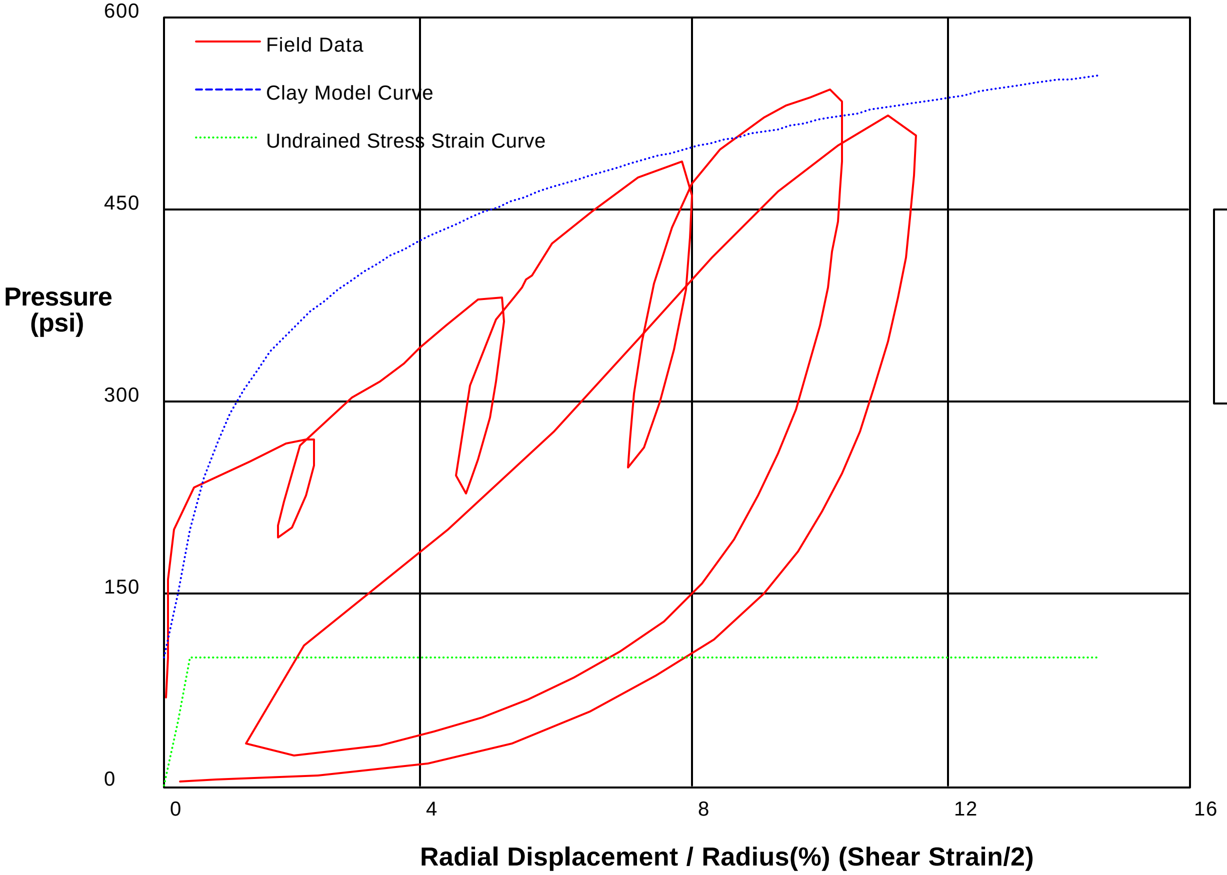
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee, Inc.**

King County Brightwater Phase II **November 12, 2004**

Hole No. P-502 **Depth 72 ft** **File C:\DATA\C-287\C-287\BWS3.P**



GIBSON'S CLAY MODEL

Shear Strength 100 psi
Insitu Stress 100 psi
Shear Modulus 12000 psi

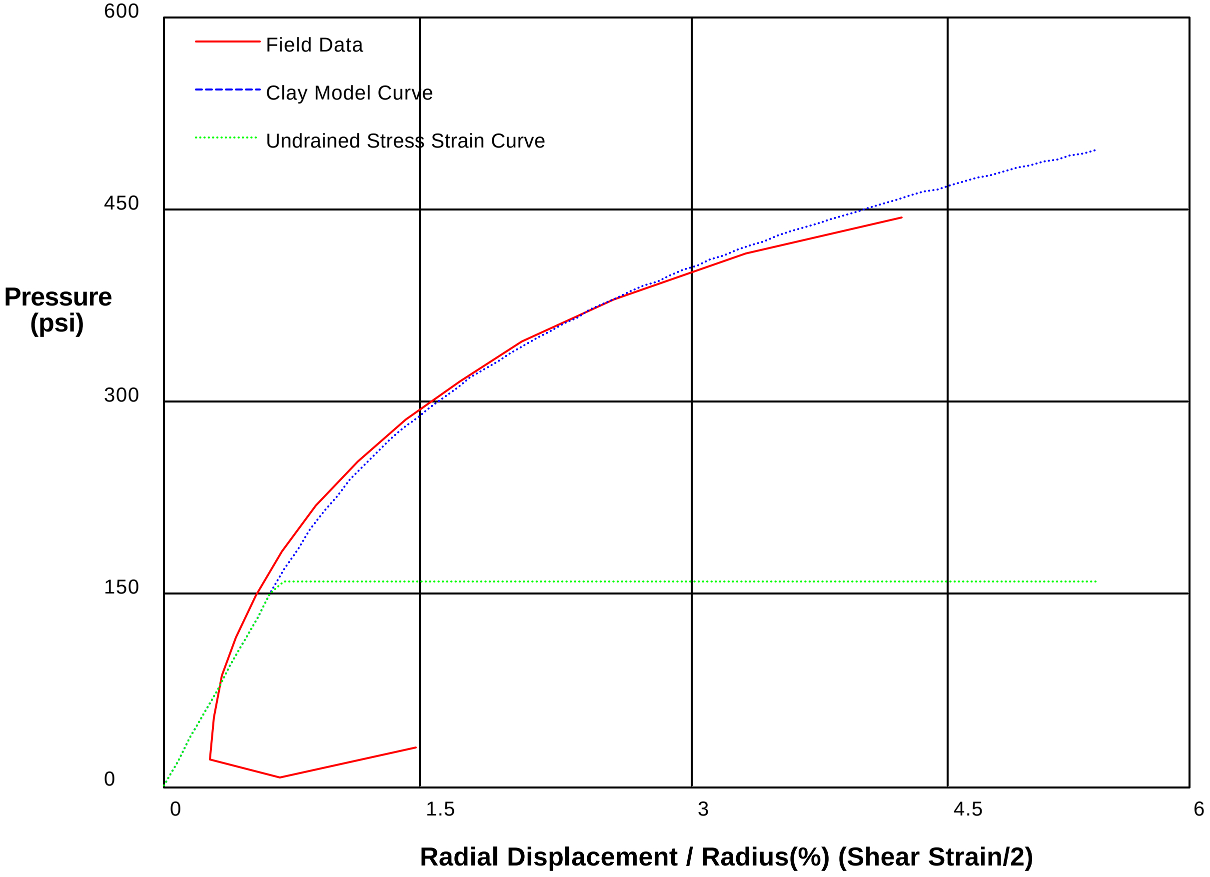
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Projecct Phase II **November 12, 2004**

Hole No. P-502 **Depth 72 ft** **File C:\DATA\C-287\C-287\BWS3E.P**



GIBSON'S CLAY MODEL

Shear Strength	**160**	**psi**
Insitu Stress	**0**	**psi**
Shear Modulus	**12000**	**psi**

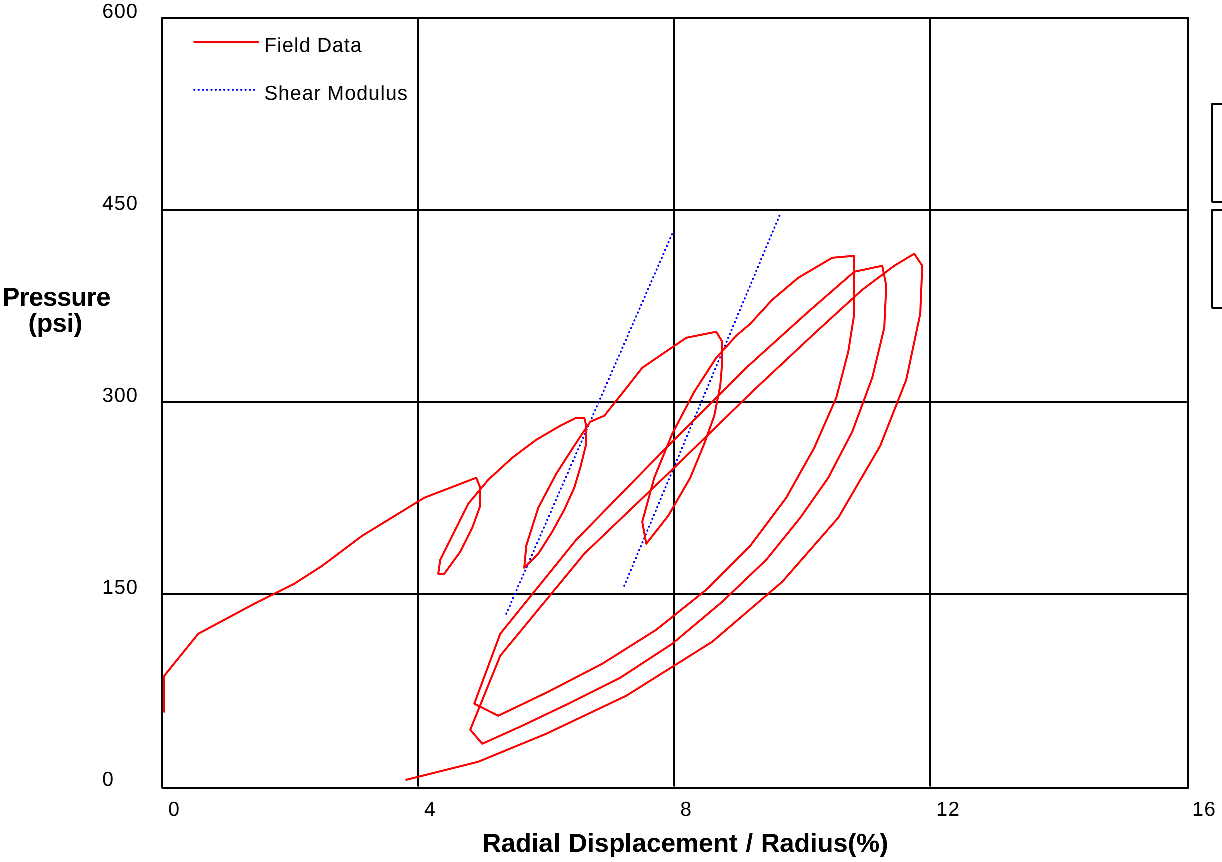
shift 8

HUGHES

PRESSUREMETER DATA **Camp Dresser & McKee, Inc.**

King County Brightwater Project Phase II **November 12, 2004**

Hole No. P5-02 **Depth 70.5 ft** **File C:\DATA\C-287\BWS4.P**



Shear Modulus 5961 psi

Shear Modulus 5725 psi

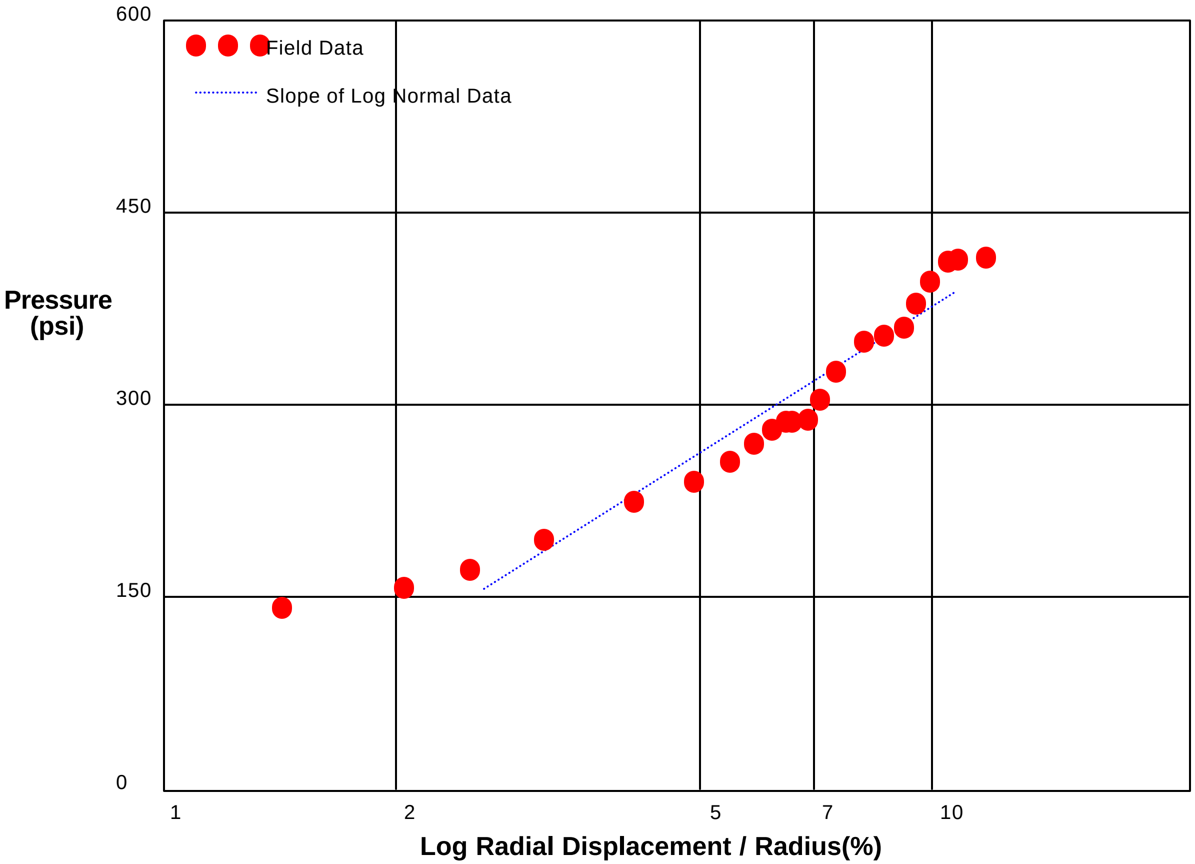
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Projecty Phase II **November 12, 2004**

Hole No. P-502 **Depth 70.5 ft** **File C:\DATA\C-287\C-287\BWS4.P**



Shear Strength 164.6 psi
Limit Pressure 609 psi

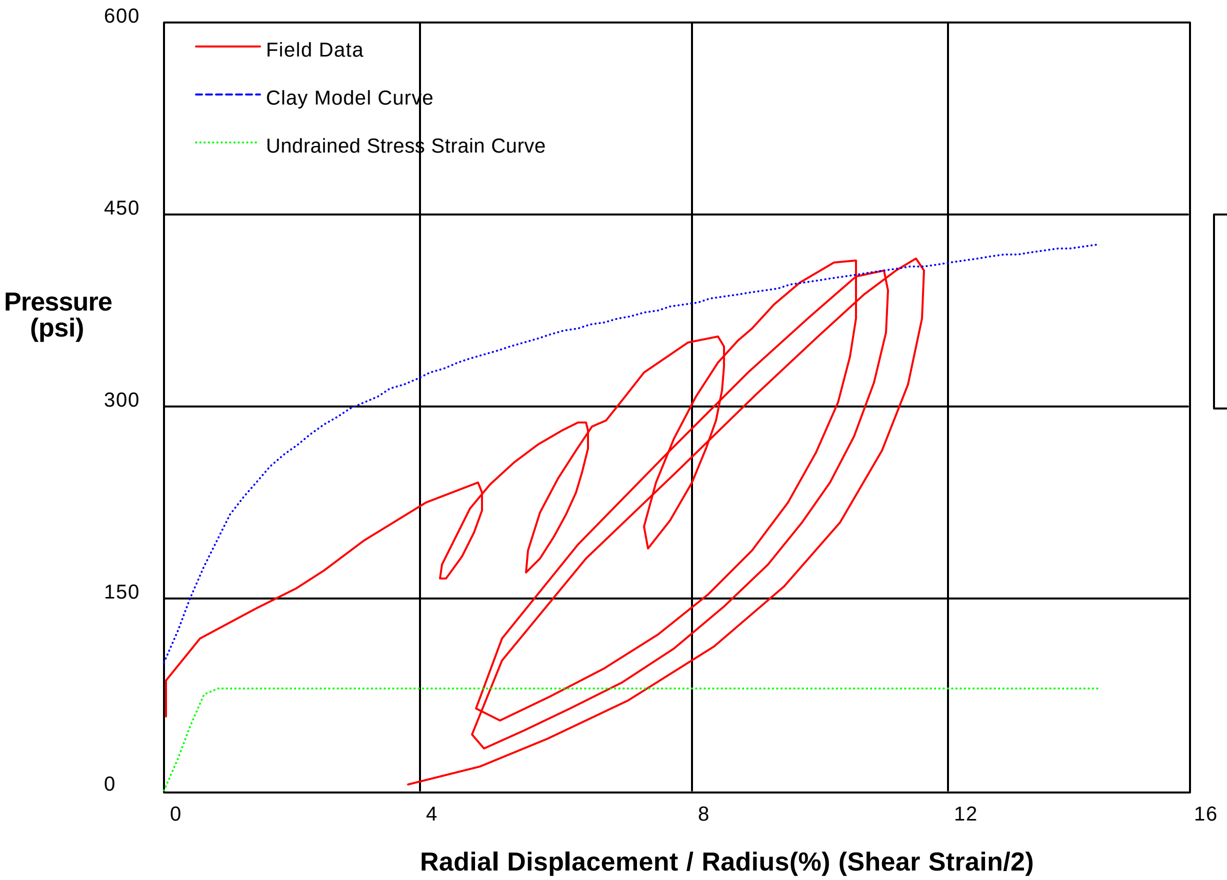
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee, Inc.**

King County Brightwater Phase II **November 12, 2004**

Hole No. P-502 **Depth 70.5 ft** **File C:\DATA\C-287\C-287\BWS4.P**



GIBSON'S CLAY MODEL

Shear Strength	**80**	**psi**
Insitu Stress	**100**	**psi**
Shear Modulus	**6000**	**psi**

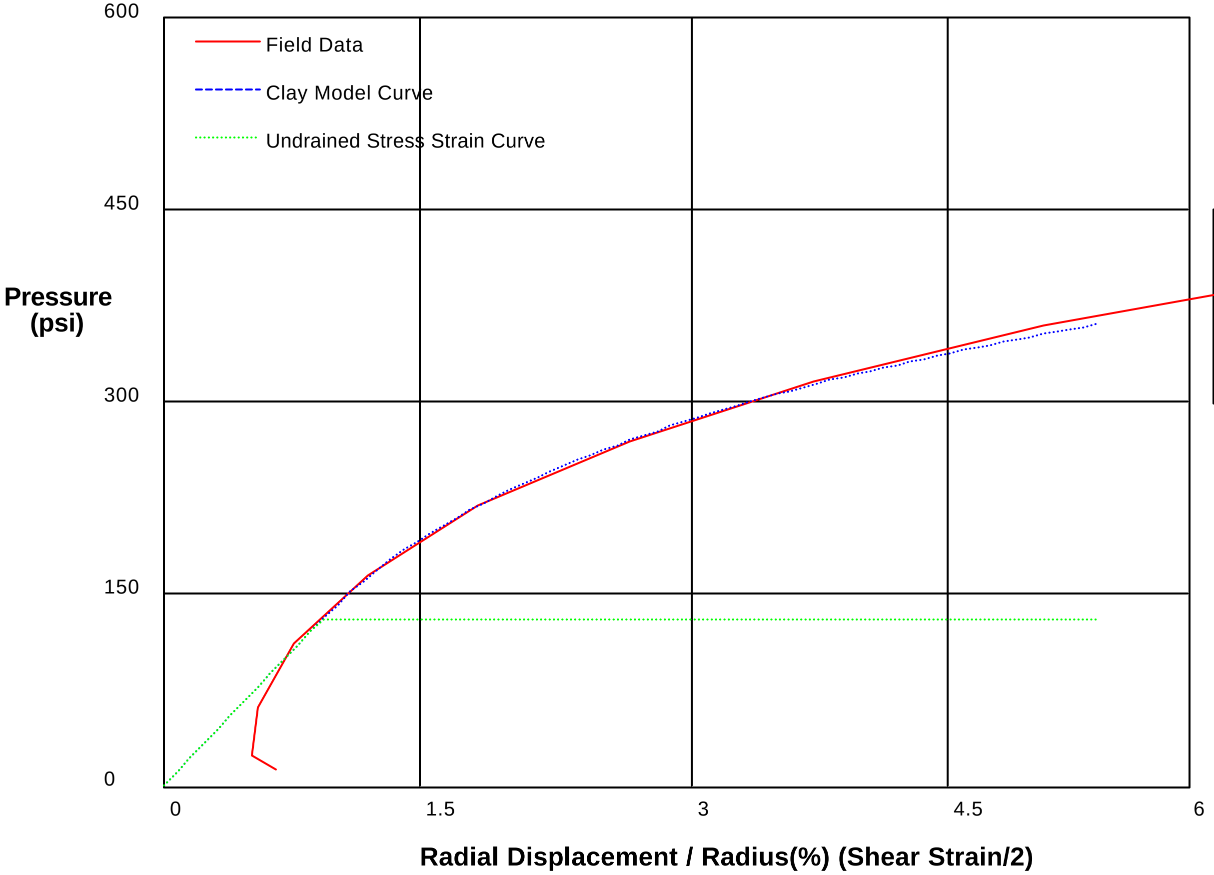
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Projecct Phase II **November 12, 2004**

Hole No. P-502 **Depth 70.5 ft** **File C:\DATA\C-287\C-287\BWS4E.P**



GIBSON'S CLAY MODEL

Shear Strength 130 psi
Insitu Stress 0 psi
Shear Modulus 7000 psi

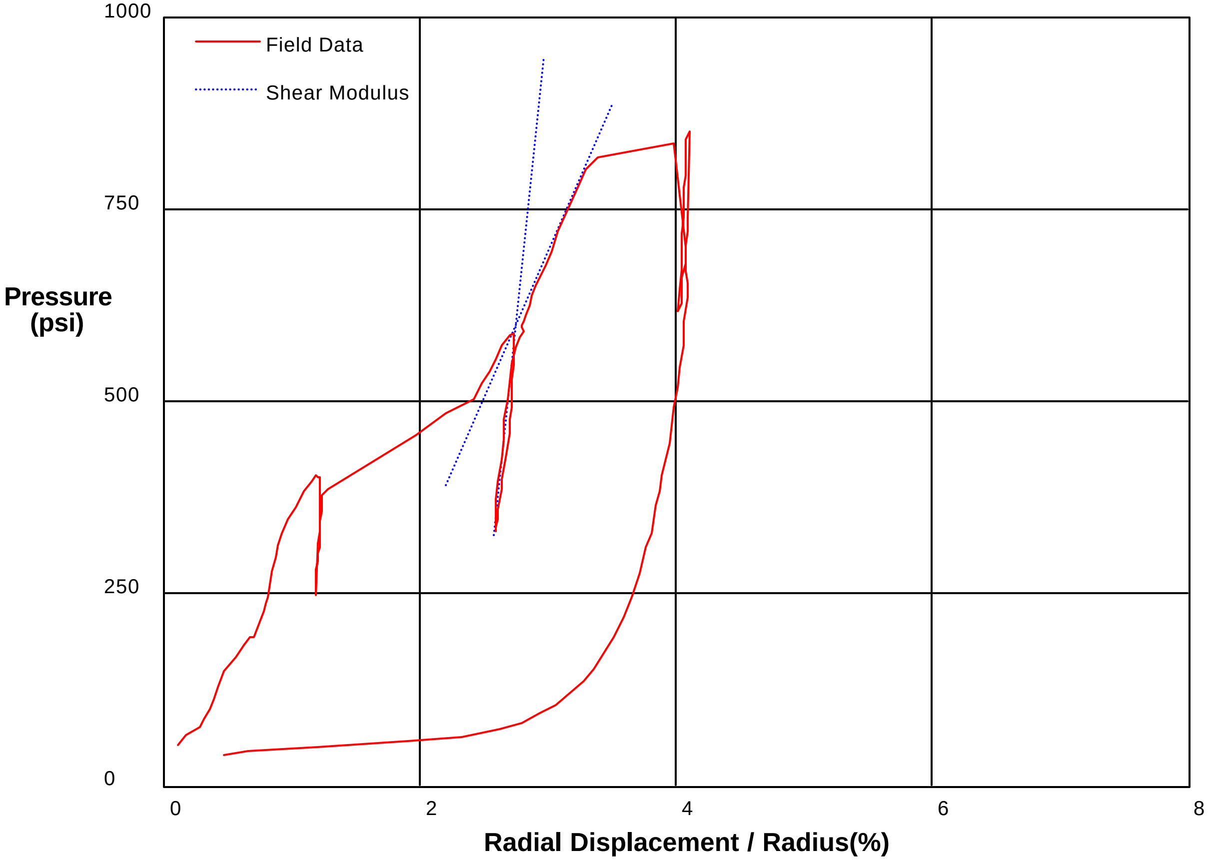
shift 7.6

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Project Phase II **11-15-04**

Hole No. P5-02 **Depth 159.5 feet** **File C:\DATA\C-287\BWS5.P**



Shear Modulus 80855 psi

Shear Modulus 19086 psi

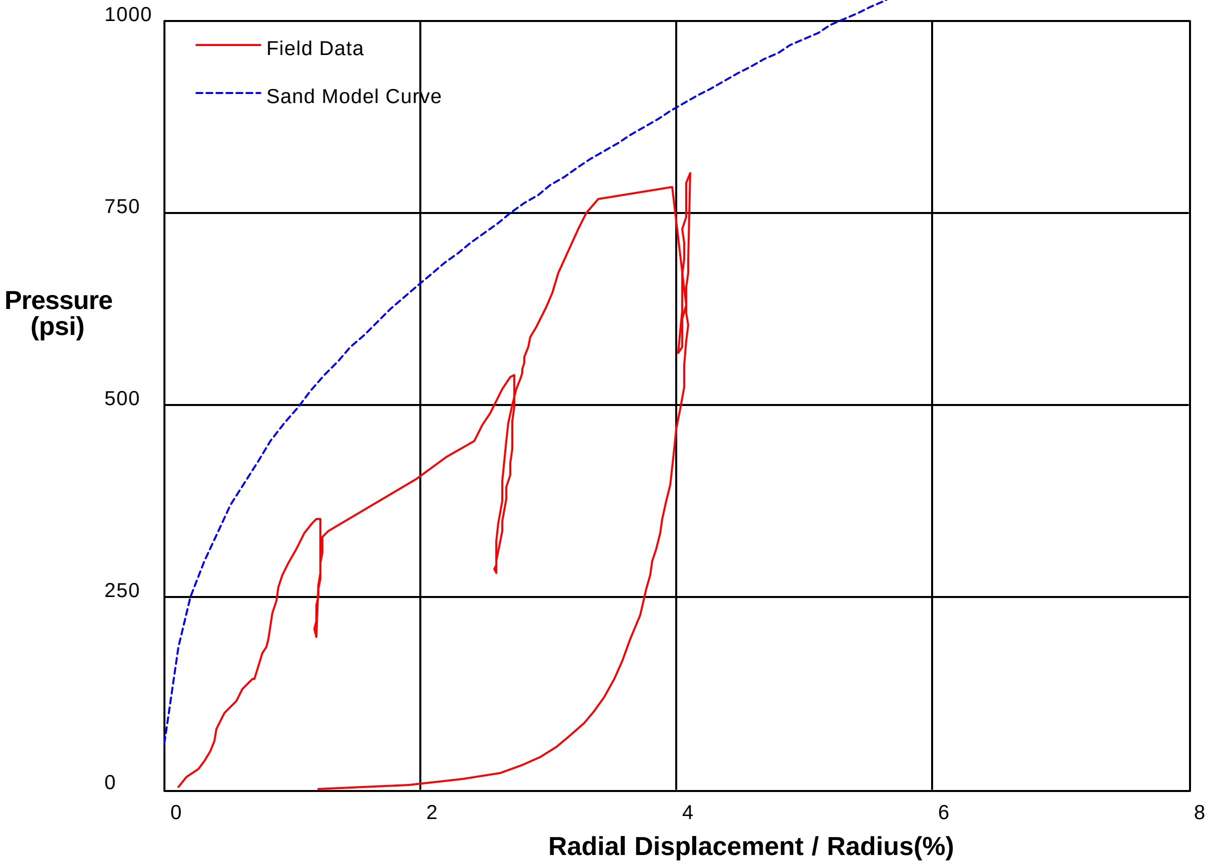
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Project Phase II **11-15-04**

Hole No. P-502 **Depth 159.5 feet** **File C:\DATA\C-287\C-287\BWS5.P**



THE HUGHES SAND MODEL

Water Pressure	**50 psi**
Friction Angle	**38 deg**
Critical Friction Angle	**32 deg**
Lateral Stress	**60 psi**
Shear Modulus	**80000 psi**

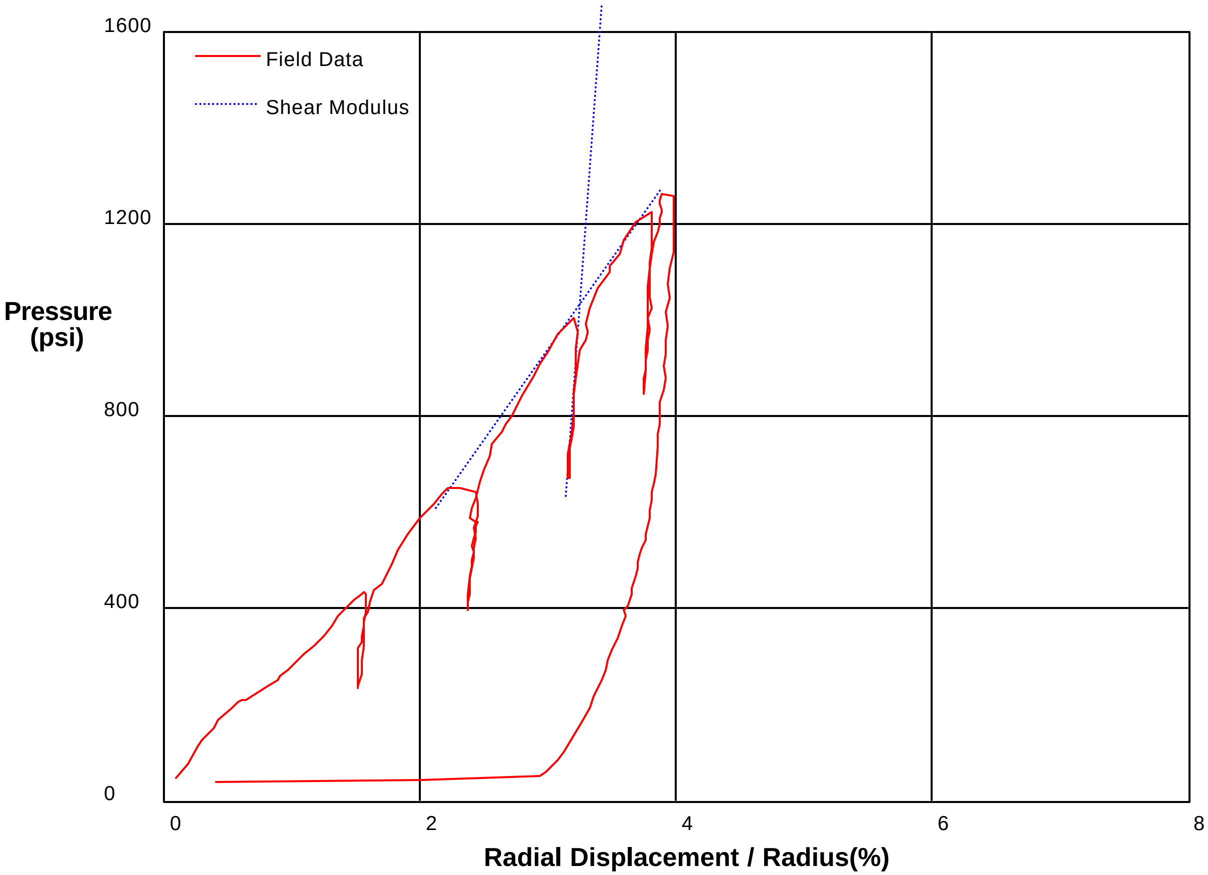
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc**

King County Brightwater Project Phase II **11-16-04**

Hole No. P5-02 **Depth 184 feet** **File C:\DATA\C-287\BWS6.P**



Shear Modulus 182222 psi

Shear Modulus 18856 psi

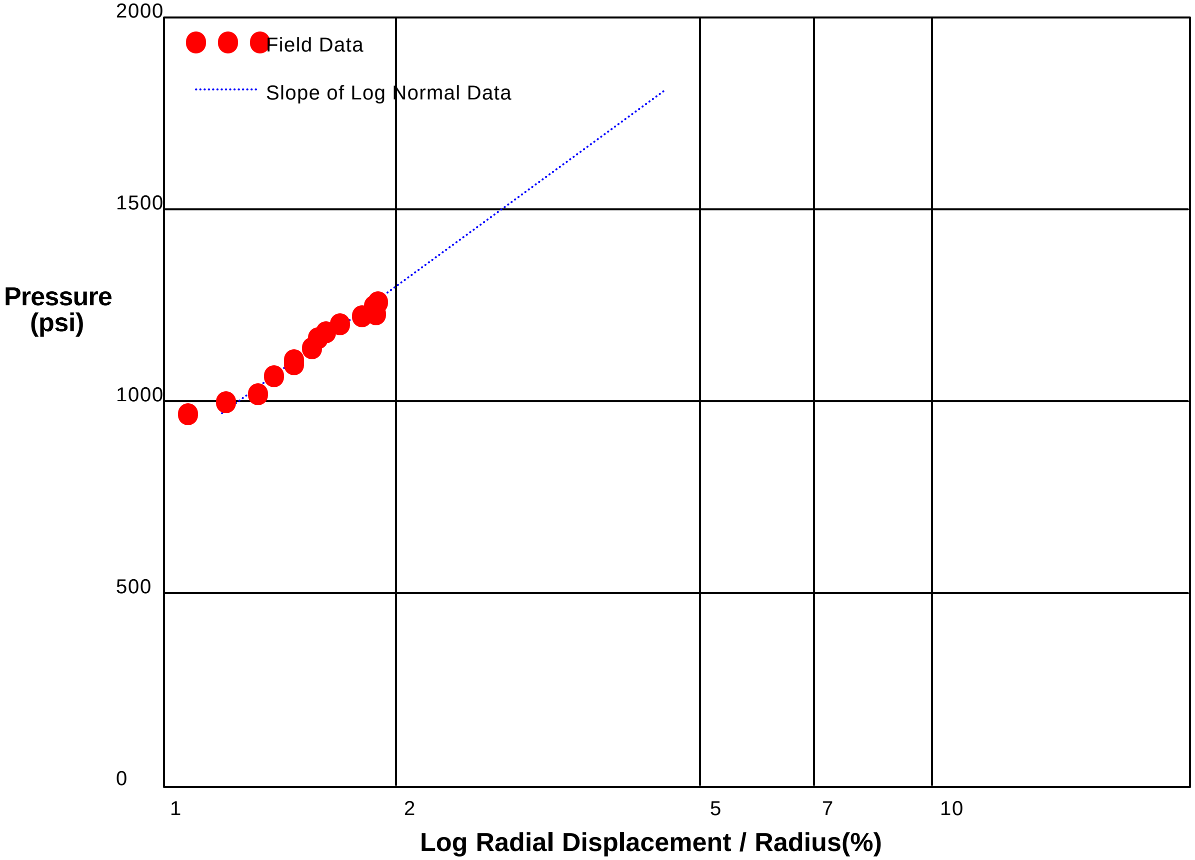
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Project Phase II **11-16-04**

Hole No. P 502 **Depth 184 feet** **File C:\DATA\C-287\C-287\BWS6.P**



Shear Strength 633.8 psi
Limit Pressure 3214 psi

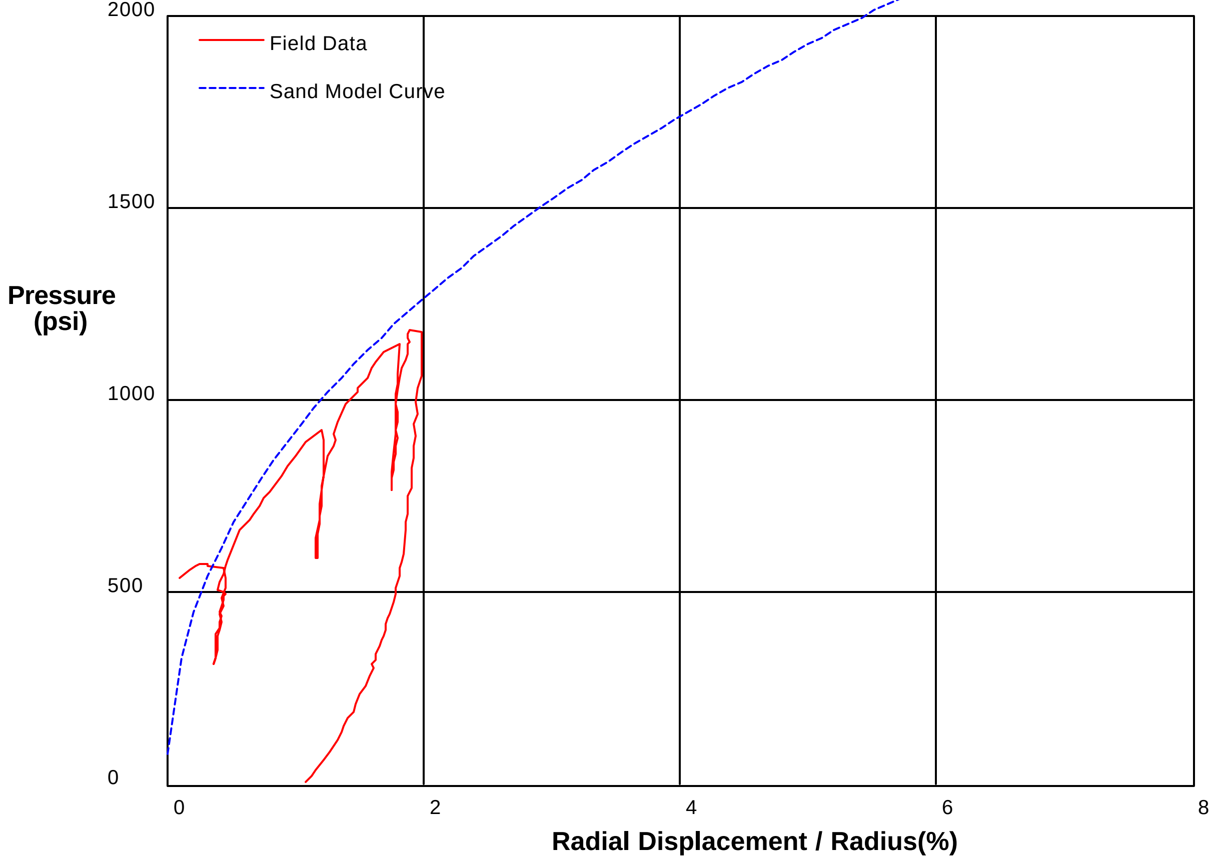
shift 2

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Project Phase II **11-16-04**

Hole No. P-502 **Depth 184 feet** **File C:\DATA\C-287\C-287\BWS6.P**



THE HUGHES SAND MODEL

Water Pressure	**80 psi**
Friction Angle	**40 deg**
Critical Friction Angle	**32 deg**
Lateral Stress	**80 psi**
Shear Modulus	**180000 psi**

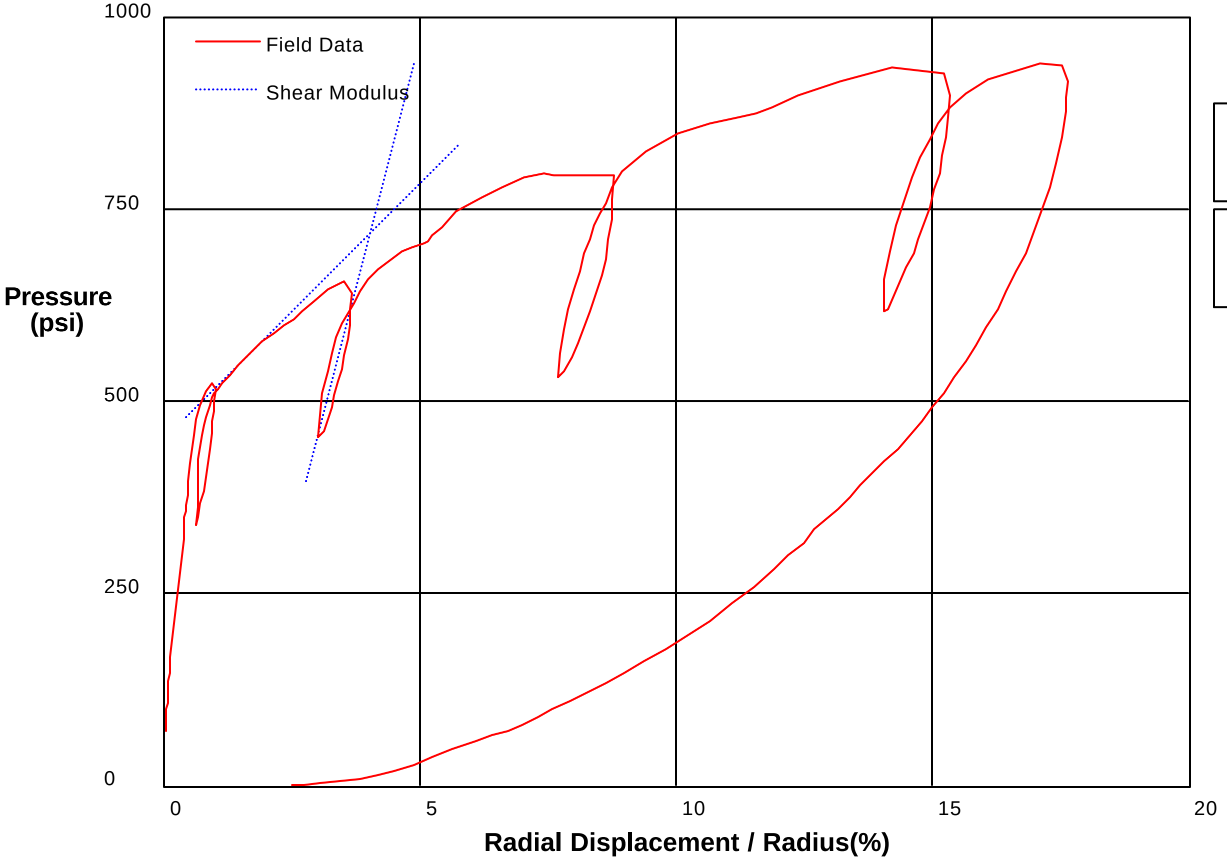
shift 2

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Project Phase II **11-16-04**

Hole No. P5-02 **Depth 205 feet** **File C:\DATA\C-287\BWS7.P**



Shear Modulus 12764 psi

Shear Modulus 3333 psi

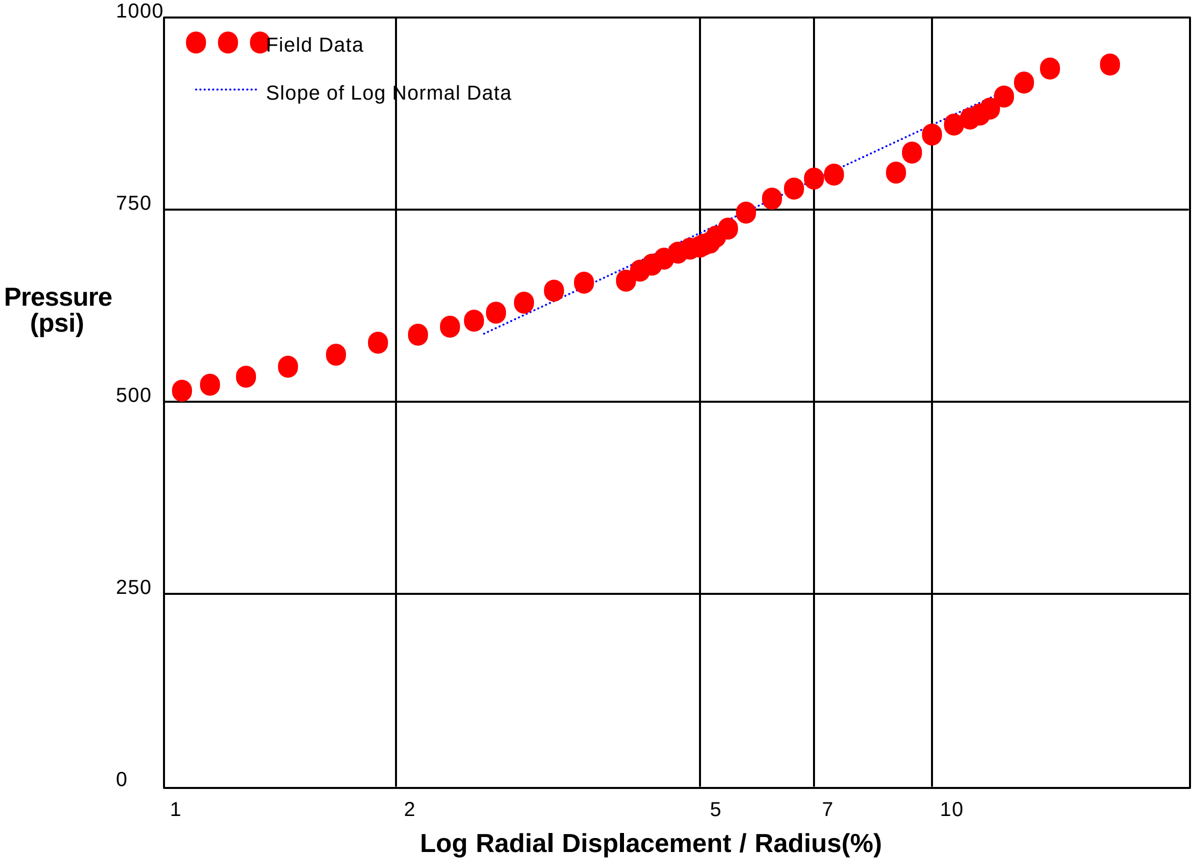
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Project Phase II **11-16-04**

Hole No. P5-02 **Depth 205 feet** **File C:\DATA\C-287\BWS7.P**



Shear Strength 202.2 psi
Limit Pressure 1147 psi

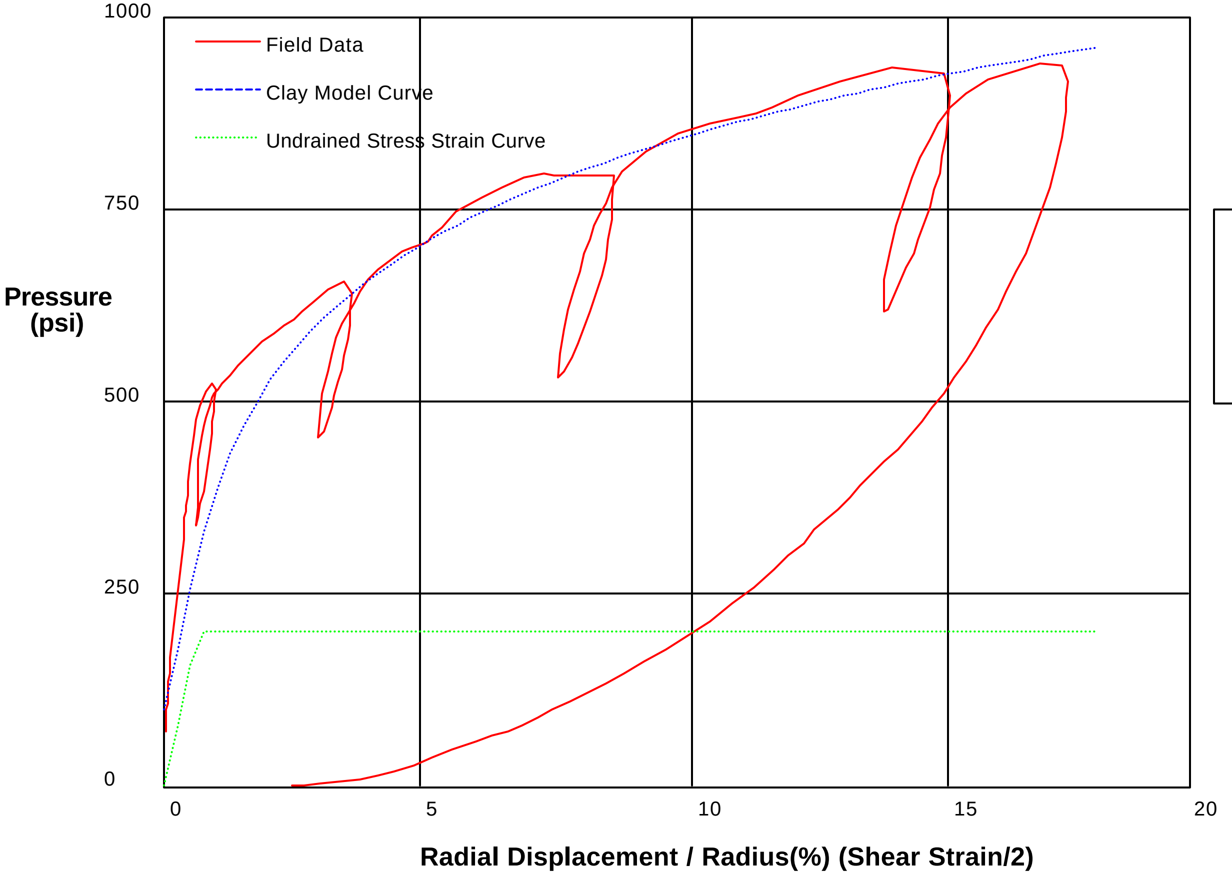
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Project Phase II **11-16-04**

Hole No. P5-02 **Depth 205 feet** **File C:\DATA\C-287\BWS7.P**



GIBSON'S CLAY MODEL

Shear Strength	**200**	**psi**
Insitu Stress	**100**	**psi**
Shear Modulus	**15000**	**psi**

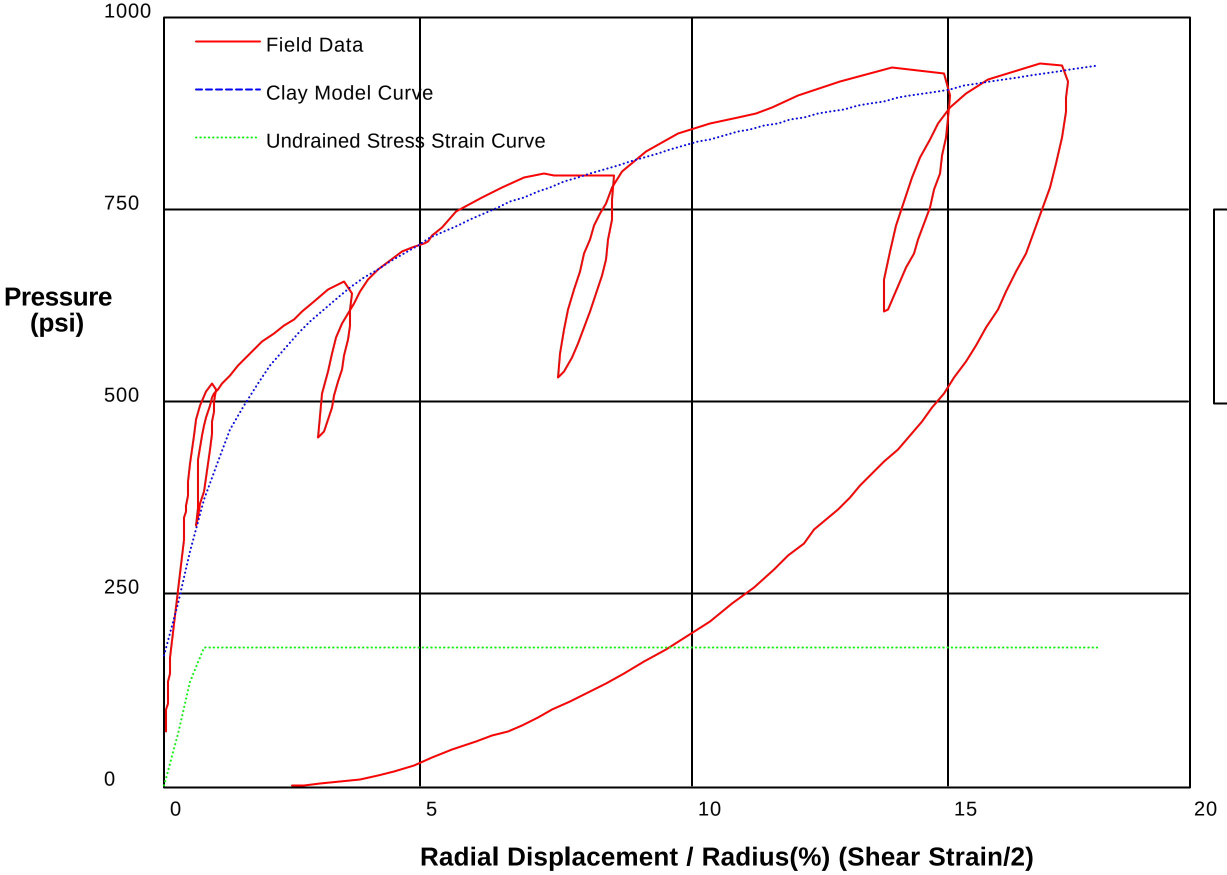
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee, Inc.**

King County Brightwater Phase II **11-16-04**

Hole No. P-502 **Depth 205 feet** **File C:\DATA\C-287\C-287\BWS7.P**



GIBSON'S CLAY MODEL

Shear Strength 180 psi
Insitu Stress 170 psi
Shear Modulus 13000 psi

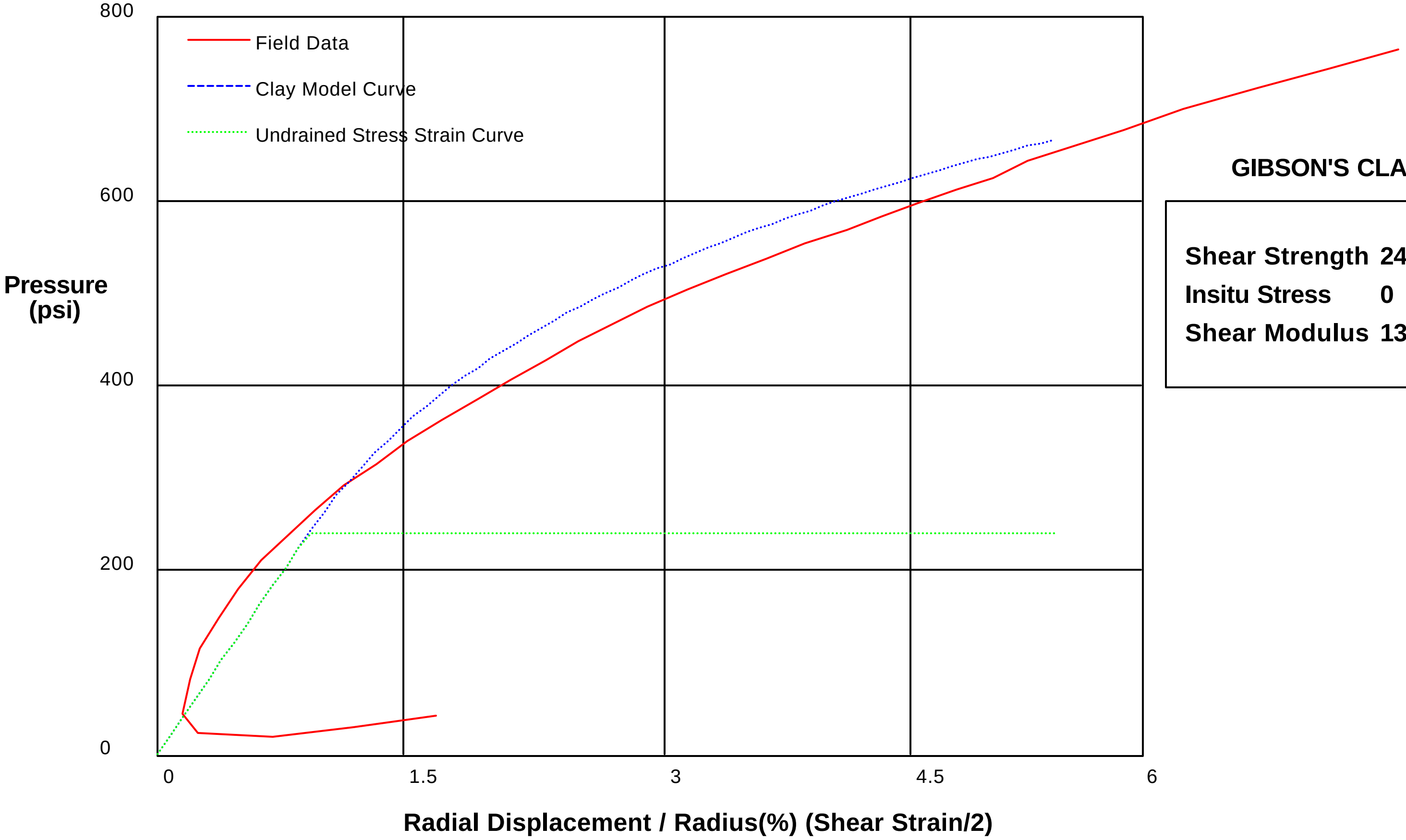
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Projecct Phase II **11-16-04**

Hole No. P-502 **Depth 205 feet** **File C:\DATA\C-287\C-287\BWS7E.P**



GIBSON'S CLAY MODEL

Shear Strength 240 psi
Insitu Stress 0 psi
Shear Modulus 13000 psi

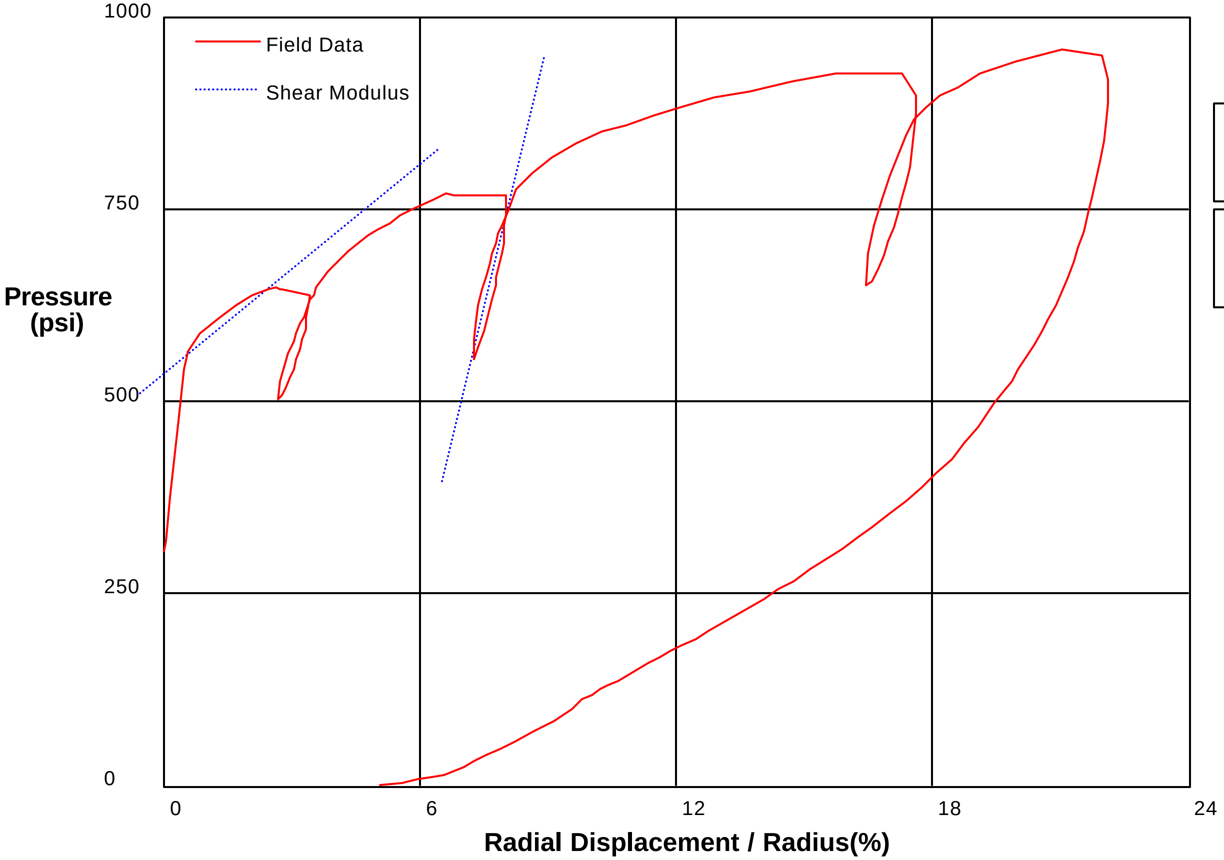
shift 2.2

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Project Phase II **11-16-04**

Hole No. P5-02 **Depth 203.5 feet** **File C:\DATA\C-287\BWS8.P**



Shear Modulus 11507 psi

Shear Modulus 2281 psi

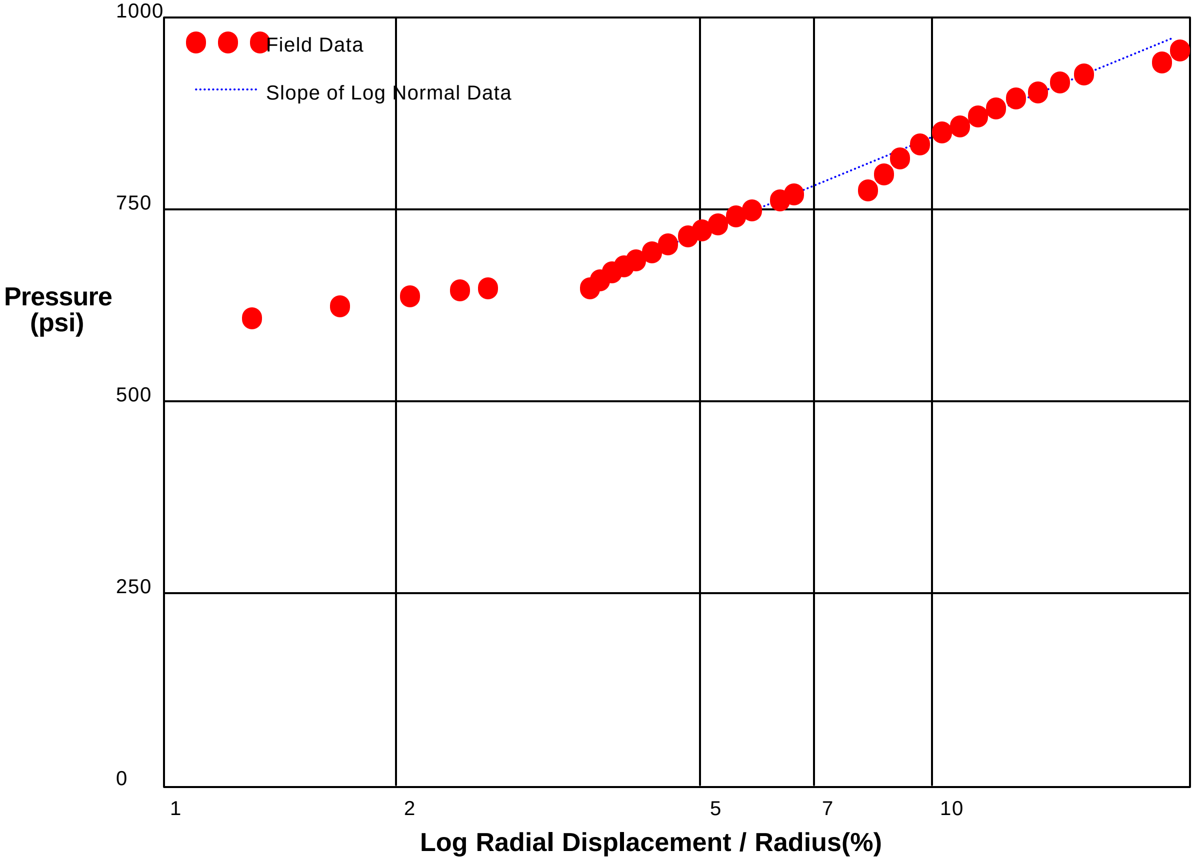
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Project Phase II **11-16-04**

Hole No. P5-02 **Depth 203.5 feet** **File C:\DATA\C-287\BWS8.P**



Shear Strength 178.8 psi
Limit Pressure 1097 psi

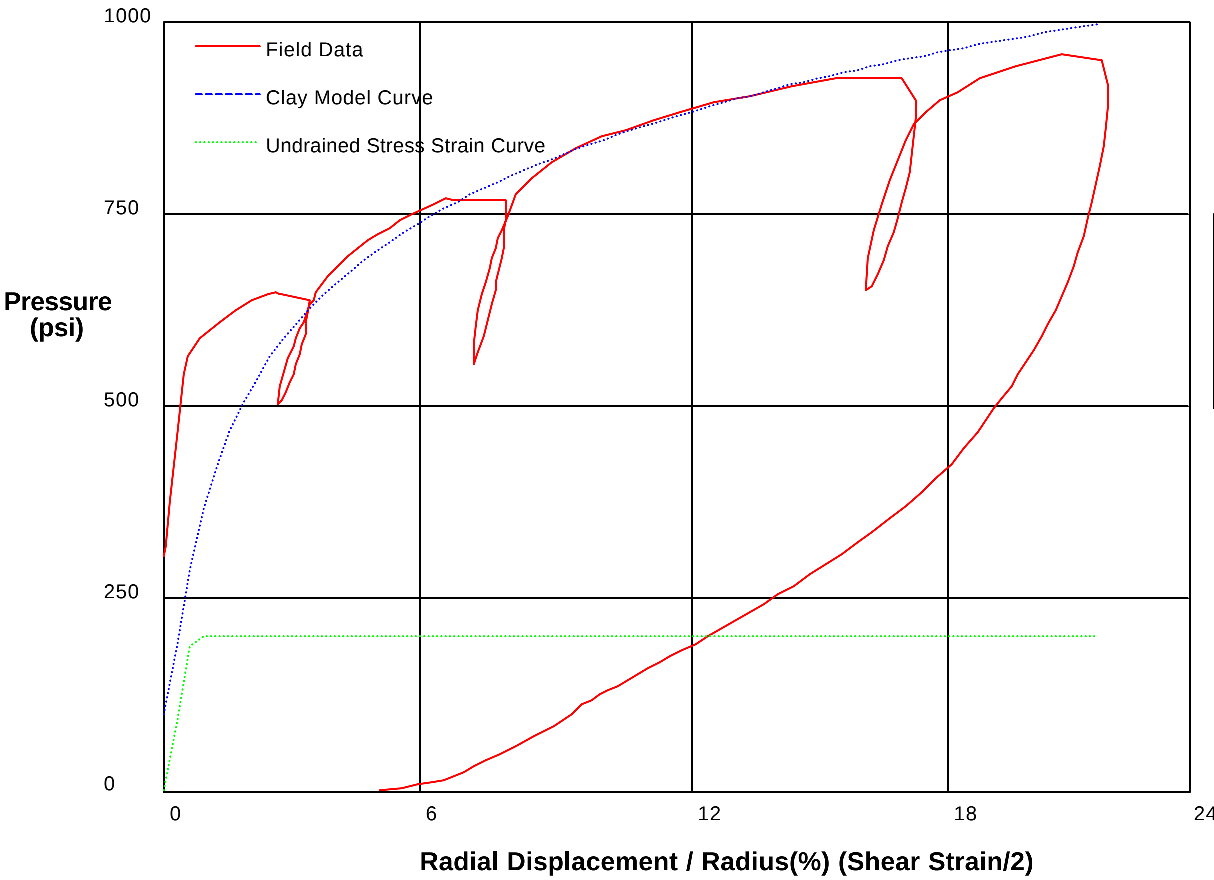
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Project Phase II **11-16-04**

Hole No. P5-02 **Depth 203.5 feet** **File C:\DATA\C-287\BWS8.P**



GIBSON'S CLAY MODEL

Shear Strength 200 psi
Insitu Stress 100 psi
Shear Modulus 15000 psi

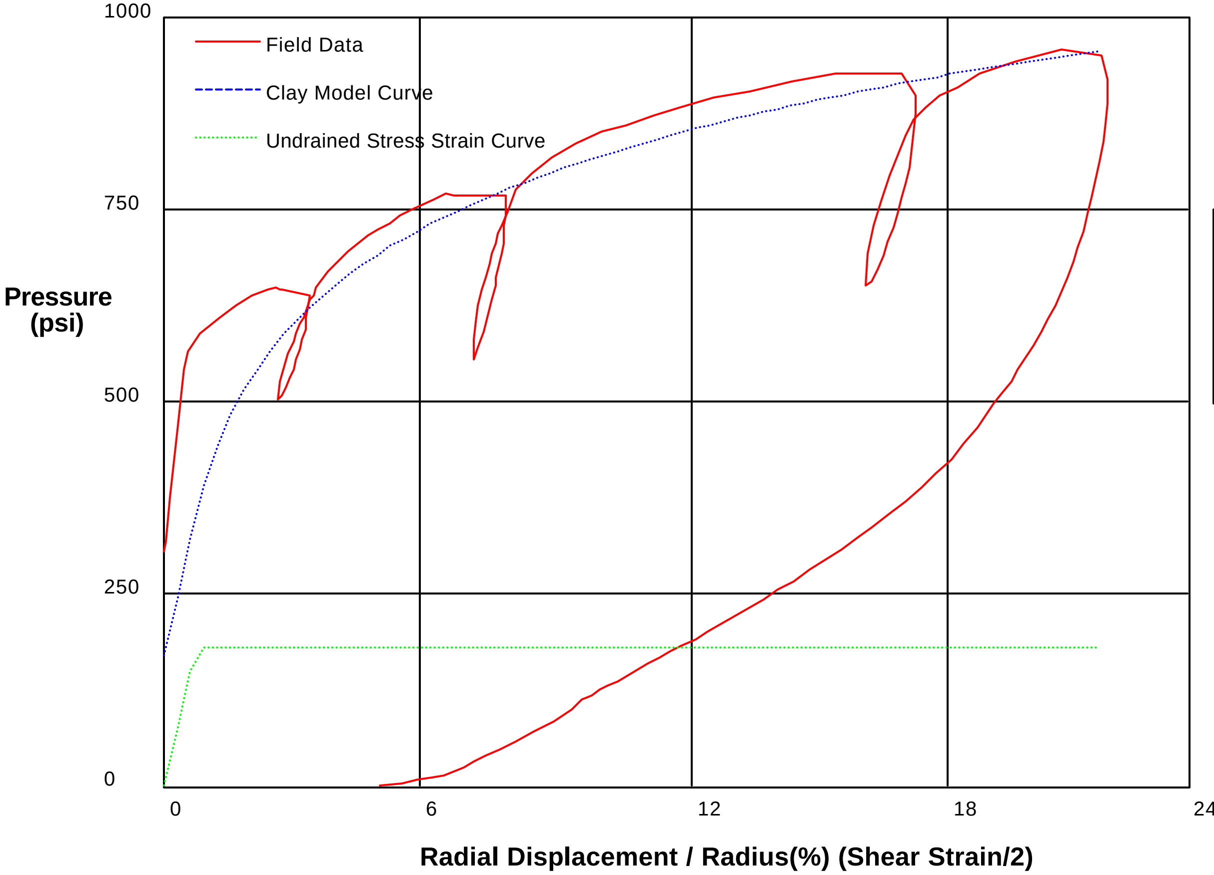
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee, Inc.**

King County Brightwater Phase II **11-16-04**

Hole No. P-502 **Depth 203.5 feet** **File C:\DATA\C-287\C-287\BWS8.P**



GIBSON'S CLAY MODEL

Shear Strength	**180**	**psi**
Insitu Stress	**170**	**psi**
Shear Modulus	**12000**	**psi**

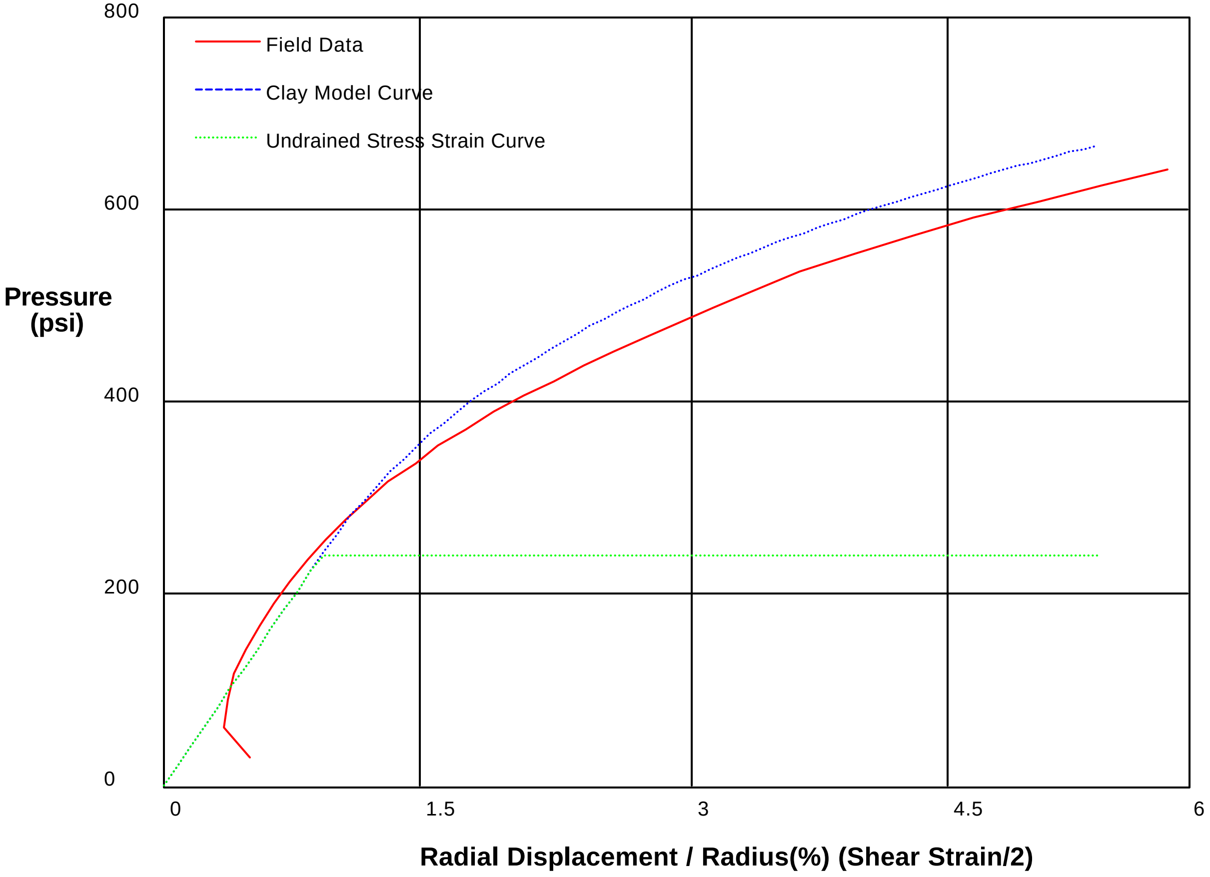
shift 0

HUGHES

PRESSUREMETER DATA **Camp Dresser & Mckee Inc.**

King County Brightwater Projecct Phase II **11-16-04**

Hole No. P-502 **Depth 203.5 feet** **File C:\DATA\C-287\C-287\BWS8E.P**



GIBSON'S CLAY MODEL

Shear Strength 240 psi
Insitu Stress 0 psi
Shear Modulus 13000 psi

shift-2.5

HUGHES