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January 17, 1991

RTK Joint Venture
1800 Harrison Street
Oakland, CA 94623-2321

Attention: Dr. Mack Riddle

Subject: Report on "Engineering Properties of Geologic Materials from Superconducting Super Collider Project", Prototype Installation Facility (PIF), by Professor G. Mesri, University of Illinois, Urbana Report No. SSC-GR-82

Dear Mack,

We are herewith transmitting 19 copies of the above report. Please call me if you have any questions.

Very truly yours,

THE EARTH TECHNOLOGY CORPORATION

Matthew L. Werner, Ph.D.
Associate - Geosciences

enclosure

werner.a\ssc2

Engineering Properties of Geologic Materials

From

Superconducting Super Collider Project

Waxahachie, Texas

Final Report

Submitted to

Earth Technology Corporation

P. O. Box 22785

Long Beach, CA 90802-5785

Contract No. SP-3134

Supplemental Agreement No. 2

PIF Program

Submitted by

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December 20, 1990

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Engineering Properties of Eagle Ford Shale
from the SSC Project, PIF Program

1. Introduction

This is the Final Report for Consultant Agreement No. SP-3134, Supplemental Agreement No. 2, with the Earth Technology Corporation, Long Beach, California. It includes data on mineralogy, natural water content, total unit weight, dry unit weight, Atterberg plastic and liquid limits, undrained shear strength, undrained modulus, swelling pressure, recompression index, swelling index, and deterioration characteristics of Eagle Ford shale specimens prepared from NX core size samples.

This report includes results of 12 Atterberg plastic and liquid limit tests, 14 unconsolidated undrained triaxial compression tests, 9 oedometer tests, 16 duplicate environmental controlled deterioration tests, and mineralogy determinations. Natural water content was determined for specimens used for all tests, and initial degree of saturation and dry unit weight were determined for all triaxial compression and oedometer specimens.

The detailed description of laboratory testing procedures (Report No. 3, July 1990) as well as the quality assurance documentation of laboratory test procedures are included in Appendix AI and BI for reference.

2. Geologic Materials

NX-core samples of Eagle Ford shale (EFS) which were received from the Earth Technology Corporation, and tested, are listed in Table 1. This table includes information on Boring Number and Depth of Samples, as well as the date they were received. These samples were inspected when received, resealed if

necessary, and stored in a temperature and humidity controlled room (T = 15°C, RH = 96%) until they were tested.

3. Mineralogical Analyses

Results of mineralogical analyses on an Eagle Ford shale sample from a shear zone, as well as on a Bentonite sample on which direct shear tests have been carried out (Final Report, August 25, 1990) are shown in Table 2. The Eagle Ford shale from the shear zone contains mainly clay minerals and quartz, with some K-feldspar and pyrite. The clay minerals (in < 2μm size fraction) consist of illite, smectite and kaolinite. The smectite in EFS contains randomly interstratified illite/smectite, with 75% smectite layers.

The mineralogy determination on the Bentonite sample was carried out in order to explain relatively high residual friction angle of this material. Mineralogical analysis indicates that the sample consists of clay mineral smectite. However, there are indications that the bentonite sample includes coarse-grained mica, which probably is biotite.

4. Index Properties

Table 3 summarizes data on index properties of samples of Eagle Ford shale. This table includes data on natural water content, w_o, total unit weight, γ, dry unit weight, γ_d, liquid limit, LL, plastic limit, PL, plasticity index, PI, and initial degree of saturation, S_r. For Eagle Ford shale samples which were tested w_o = 15.7-18.9%, γ = 131-137 pcf, γ_d = 111-118 pcf, PL = 20-35%, LL = 98-139%, PI = 69-111%, and S_r = 86-99%. All Atterberg limit samples were air dried and ball-milled until all sample passed No. 200 sieve. The initial degree

of saturation of EFS samples was calculated from the measurements of specimen weights and dimensions, together with the specific gravity of solids of 2.78.

5. Unconsolidated Undrained Triaxial Compression Tests

The results of unconsolidated undrained triaxial compression tests are summarized in Table 4. The stress-strain curves for all of the tests are presented in Appendix CI, Figs. C1-C14. Photographs of shale specimens at the end of unconsolidated undrained triaxial compression tests are included in Fig. C15.

Unconsolidated undrained triaxial compression tests were performed using intact specimens with a nominal diameter of 50 mm and height to diameter ratio of 2. The nominal rate of platen displacement during unconsolidated undrained triaxial compression tests was 0.01 inch/minute. Photographs in Fig. C15 show that, for the confining pressure range of 689 kPa to 2758 kPa, used in our tests, a predominant inclined failure plane (or planes in some specimens) formed during triaxial compression tests. Table 4 includes data on natural water content, w_o, Atterberg plastic and liquid limits, as well as compressive strength, $(\sigma_1-\sigma_3)_{max}$, undrained modulus E_u, and undrained modulus to undrained shear strength ratio E_u/s_u. Undrained shear strength is defined as $s_u = s_u(UU) = (\sigma_1-\sigma_3)_{max}/2$, and undrained modulus was calculated as a secant slope between zero axial strain and the axial strain at 50% of the peak strength. Table 4 also includes the magnitude of the total confining pressures 689-2758 kPa, and the time to peak strength, 14-21 minutes.

For Eagle Ford shale samples s_u = 673-1419 kPa, E_u = 250-673 MPa, and E_u/s_u = 289-516. The values of $s_u(UU)$, $E_u(UU)$, and $E_u(UU)/s_u(UU)$ for EFS are

plotted against natural water content in Figs. 1-4 and against initial degree of saturation in Figs. 5-7.

6. Oedometer Tests

Oedometer test results are summarized in Table 5, and void ratio-log pressure as well as swelling pressure-log time curves are presented in Appendix DI, Figs. D1-9. All tests were carried out on 45 mm diameter and 12 mm high intact specimens. The swelling pressure, σ_{si} was measured at the specimen void ratio e_i. Void ratios in the oedometer tests were calculated from the measurements of specimen initial and final total weight, dry weight, dimensions including the diameter as well as initial and final heights and axial compression, and specific gravity of solids. Table 5 includes the values of natural water content, w_o, specimen void ratio e_i, as well as the swelling pressure σ_{si}. The values of σ_{si} are in the range of 1.5-5.7 tsf (144-546 kPa). The magnitude of swelling pressure at void ratios slightly smaller than or larger than e_i can be computed using the following equation:

$$\sigma_s = \sigma_{si} \exp\left(2.3 \frac{e_i - e}{C_s} \right)$$

where C_s is the swelling index. The values of σ_{si} are plotted against natural water content, initial degree of saturation, and dry unit weight in Figs. 8-10. After reaching σ_{si} at e_i some of the specimens were subjected to incremental loading in order to measure the recompression index. Maximum effective vertical pressures of 64-126 tsf (6-12 MPa) were reached in these tests. The values of C_r are listed in Table 5 and are plotted against natural water content in Fig. 11. After reaching σ_{si} or the maximum effective vertical stress, oedometer

specimens were subjected to pressure decrements in order to measure the swelling index, C_s. The values of C_s are listed in Table 5 and are plotted against natural water content in Fig. 12. The values of the coefficient of consolidation, c_v, computed by fitting the Terzaghi theory of consolidation to the recompression increments are plotted against effective vertical stress in Fig. 13. These values may be used to estimate rate of primary recompression of Eagle Ford shale.

7. Environmental Controlled Deterioration Tests

Deterioration test results are summarized in Table 6 and are presented in terms of water content against relative humidity as well as suction pressure, and water content against time in Appendix EI, Figs. E1-8. The suction pressure u_s, in tsf, is computed using the following equation.

$$u_s = 1391 \ln (RH/100)$$

The computed suction pressure is a measure of dry or wet environment. All specimens were first subjected to RH = 96% and allowed to come to equilibrium. Then relative humidity was decreased to either 75 or 87%, and after primary drying it was further reduced to RH = 56%. Following primary drying at RH = 56% the cycle was reversed and RH was increased to 87% and then to 96%. All duplicate specimens of Eagle Ford shale, except the first two series, were subjected to two full dry-wet cycles. The first two test series were subjected to one full dry-wet cycle. In Table 6 the deterioration test results are summarized in terms of final water content under each relative humidity. In Figs. 14 and 15 water content of Eagle Ford shale are plotted against number of exposures to dry (RH = 56%) and wet (RH = 96%) conditions. These results appear

to suggest that softening at high humidity condition may be minimized by avoiding extreme conditions of wetting (i.e. RH = 99%) and drying (i.e. RH less than 50%).

All specimens of Eagle Ford shale slightly softened, but remained intact upon first exposure to RH = 96%. During drying down to RH = 56% some microfissures developed along the bedding planes. No further fissuring was observed during wetting back up to RH = 96%. During the second dry-wet cycle, although a few specimens split along bedding planes, most specimens remained substantially intact.

Eagle Ford shale is moderately fissile, with natural water contents (15-19%) and liquid limits (90-140%) that lead to an equilibrium relative humidity, ERH, of around 95%. Equilibrium relative humidity is the RH at which shale neither gains or loses moisture, thus remaining unchanged. When a shale is exposed to RH different from its ERH, along with moisture gain or loss, shale experiences anisotropic and inhomogeneous deformations leading to the opening of bedding planes and joints and formation of fissures and cracks. Anisotropic fabric and inhomogeneous composition of most shales contribute to differential swelling and shrinkage.

Deterioration behavior of shales has been correlated to the natural water content which corresponds to ERH, and equilibrium water content at RH = 97.5% both upon first exposure and after a complete dry-wet cycle, in terms of the liquid limit which is a measure of shale composition. In Fig. 16, natural water content, w_o, equilibrium water contents at RH = 97.5%, as well as the shrinkage limit, w_s, are plotted against the liquid limit, w_ℓ for two dozen shales (Mesri and Cepeda, 1990, in preparation). In general, shales with natural water contents less than the shrinkage limit are fissile, whereas shales with natural water contents higher than w_s are massive. Fissile shales (F) deteriorate by opening along bedding planes, followed by vertical splitting of thin slabs. The

massive shales (M) have no preferred orientation of discontinuities, and they often break down into chunks and chips along randomly oriented cracks, fissures, and slickensides. With certain exceptions, fissile shales generally have natural water contents less than 15% and liquid limits no greater than 100%. Shales with w_o and w_ℓ beyond this range are generally massive. Fissile (F) and massive (M) shales are further subdivided into three groups depending on the moisture content change and deterioration behavior upon exposure to different RH environments. Shales in group 1 (F1 and M1) deteriorate if they are subjected to RH wetter than ERH, whereas shales in group 3 (F3 and M3), which have ERH greater than 97.5%, deteriorate when subjected to environments drier than ERH. The shales in group 2 (F2 and M2) deteriorate at environments different from ERH.

In a previous series of deterioration tests, Eagle Ford specimens were subjected to dry-wet cycles in RH range of 45 to 99% (Final Report to ETC, August, 1990). Equilibrium relative humidity of EFS was estimated to be around 95%. In the present series of deterioration tests RH was within 56 to 96%. After two full dry-wet cycles, the present series of specimens have deteriorated much less than those in the previous series. This behavior is consistent with an ERH near 95%.

Table 1 Samples of Eagle Ford Shale Received and Tested

Boring	Depth (ft)	Date Received
B 1617	203.90 - 204.90	6 - 29 - 90
B 1617	204.90 - 205.55	6 - 29 - 90
B 1637	202.35 - 203.75	7 - 5 - 90
B 1637	203.75 - 205.50	7 - 5 - 90
B 1637	206.80 - 207.90	7 - 5 - 90
B 1657	192.95 - 194.45	7 - 10 - 90
B 1597	215.75 - 217.50	7 - 10 - 90
B 1697	109.00 - 110.60	7 - 10 - 90
B 1697	110.60 - 111.50	7 - 10 - 90
B 1619	204.25 - 205.80	7 - 13 - 90
B 1619	206.55 - 207.50	7 - 13 - 90
BC1	206.70 - 207.60	7 - 13 - 90
BC1	207.60 - 209.50	7 - 13 - 90
BF1A	162.40 - 163.50	7 - 18 - 90
BF1A	165.30 - 166.20	7 - 18 - 90

Table 2A Whole Sample Mineralogy

Material	Bore Hole	Depth ft	Clay	Qtz	K-spar	Pyr
EFS	B1697	110.60-111.50	59	32	7	2
BEN	BIR43	116.90-117.85	100*			

Numbers represent mineral abundance in weight percent
EFS = Eagle Ford shale from a shear zone,
BEN = Bentonite used in the direct shear test (Final Report, August 1990)
Clay = Total clay minerals,
Qtz = Quartz,
K-spar = Potassium feldspar,
Pyr = pyrite,

* Bentonite sample includes coarse-grained mica, prohbably biotite.

Table 2B Clay Mineralogy (< 2μm)

Material	Bore Hole	Depth ft	Ill	Kaol	Smect	Smectite Hydration State	Development of Hydroxy Interlayer in Smectite
EFS	B1697	110.60-111.50	50	16	34*	2 H_2O	Minor
BEN	BIR43	116.90-117.85			100	2 H_2O	Minor

Numbers represent mineral abundance in weight percent
Ill = Illite,
Kaol = Kaolinite,
Smect = Smectite,

* Contains randomly interstratified illite/smectite with 75% smectite layers

Table 3 Index Properties of Core Samples

Boring	Depth (ft)	Material	w_o (%)	LL (%)	PL (%)	PI (%)	γ (pcf)	γ_{dry} (pcf)	S_r (%)
B 1617	204.90–205.65	EFS	17.7	139	35	104	136	116	99
BF1A	162.40–163.50	EFS	17.4	128	33	95	135	115	95
BF1A	165.30–166.20	EFS	16.9	120	28	92	137	117	97
BF1A	165.30–166.20	EFS	17.5	136	25	111	131	111	86
B 1697	109.00–110.60	EFS	18.5	122	28	94	133	112	94
B 1697	110.60–111.50	EFS	18.3	134	31	103	133	113	95
B 1637	203.75–205.50	EFS	17.1	122	20	102	135	115	93
B 1637	203.75–205.60	EFS	15.8	123	28	95	136	118	93
B 1637	206.80–207.90	EFS	16.2	119	29	90	135	116	91
BC1	207.60–209.50	EFS	18.9	126	27	99	133	112	96
BC1	207.60–209.50	EFS	18.5	126	27	99	131	111	91
BC1	207.60–209.50	EFS	17.9	126	27	99	134	114	95
B 1619	204.25–205.80	EFS	15.7	98	28	70	137	118	93
B 1657	192.95–194.45	EFS	16.9	99	30	69	135	116	95

Note : All the samples for Atterberg Limit tests were prepared by air–drying and then pulverizing by ball milling

Table 4 Summary of Unconsolidated Undrained Triaxial Compression (UU) Test Results

Test No.	Boring	Depth (ft)	Material	w_o (%)	L L (%)	P L (%)	γ (pcf)	γ_{dry} (pcf)	S_r (%)	σ_3 (kPa)	$(\sigma_1-\sigma_3)_{max}$ (kPa)	s_u (kPa)	E_u (MPa)	E_u/s_u	t_f (min.)
PIF UU1	B 1617	204.90–205.65	EFS	17.7	139	35	136	116	99	1378	2675	1337	420	314	20
PIF UU2	BF1A	162.40–163.50	EFS	17.4	128	33	135	115	95	689	2648	1324	460	352	14
PIF UU3	BF1A	165.30–166.20	EFS	16.9	120	28	137	117	97	1378	2606	1303	673	516	16
PIF UU4	BF1A	165.30–166.20	EFS	17.5	136	25	131	111	86	2756	2339	1169	600	513	14
PIF UU5	B 1697	109.00–110.60	EFS	18.5	122	28	133	112	94	1378	1347	673	250	371	16
PIF UU6	B 1697	110.60–111.50	EFS	18.3	134	31	133	113	95	1378	1719	859	300	349	18
PIF UU7	B 1637	203.75–205.50	EFS	17.1	122	20	135	115	94	689	2534	1267	382	301	17
PIF UU8	B 1637	203.75–205.60	EFS	15.8	123	28	136	118	93	2756	2839	1419	467	328	16

Table 4 (Cont.) Summary of Unconsolidated Undrained Triaxial Compression (UU) Test Results

Test No.	Boring	Depth (ft)	Material	w_o (%)	L L (%)	P L (%)	γ (pcf)	γ_{dry} (pcf)	S_r (%)	σ_3 (kPa)	$(\sigma_1-\sigma_3)_{max}$ (kPa)	s_u (kPa)	E_u (MPa)	E_u/s_u	t_f (min.)
PIF UU9	B 1637	206.80–207.90	EFS	16.2	119	29	135	116	91	1378	2483	1244	560	450	16
PIF U10	BC1	207.60–209.50	EFS	18.9	126	27	133	112	96	689	1350	675	317	470	16
PIF UU11	BC1	207.60–209.50	EFS	18.5	126	27	131	111	91	1378	1711	885	251	294	19
PIF UU12	BC1	207.60–209.50	EFS	17.9	126	27	134	114	95	2756	2065	1033	400	387	18
PIF UU13	B 1619	204.25–205.80	EFS	15.7	98	28	137	118	93	1378	2077	1038	300	289	14
PIF UU14	B 1657	192.95–194.45	EFS	16.9	99	30	135	116	95	1378	2435	1217	373	306	21

Table 5 Summary of Oedometer Test Results

Boring	Depth (ft)	Material	Test No.	w_o (%)	e_i	γ_{dry} (pcf)	S_r (%)	σ_{si} (Tsf)	C_r	C_s	σ_{max} (Tsf)	Loading Frame
BF1A	162.40–163.50	EFS	PIF-17	17.2	0.491	115	96	4.0	0.03–0.1	0.05	64	WF
B1697	109.00–110.00	EFS	PIF-18	18.3	0.545	112	93	3.0	0.0–0.1	0.06	64	WF
B1697	109.00–110.00	EFS	PIF-19	18.1	0.526	114	95	4.8	---	---	---	Rigid
B1657	192.95–194.45	EFS	PIF-20	16.9	0.544	112	87	1.5	0.07	0.05	64	WF
B1657	192.95–194.45	EFS	PIF-21	16.4	0.486	117	94	4.8	---	---	---	Rigid
B1637	203.75–205.50	EFS	PIF-22	17.6	0.508	115	96	5.7	0.03–0.1	0.07	245	MP
B1619	206.55–207.50	EFS	PIF-23	16.2	0.485	117	93	4.0	0.06	0.04	64	WF
B1597	215.75–217.50	EFS	PIF-24	15.6	0.475	118	91	3.5	---	0.03	---	WF
BC1	206.70–207.60	EFS	PIF-25	17.4	0.512	115	95	5.0	---	0.04	---	WF

EFS = Eagle Ford Shale WF = Wykeham Farrance Rigid = Rigid Frame MP = Multi Purpose

Table 6 Summary Summary of Deterioration Test Results

Boring	Depth (ft)	Material	Test No.	w_o %	Cycle No.	Equilibrium Water Content (%)				
						RH (%)				
						96	87	56	87	96
B1597	215.75-217.50	EFS	PIF-1	17.4	1	18.16	15.72	11.84	13.86	17.71
		EFS	PIF-2	17.4	1	18.44	16.21	13.00	14.71	18.25
B1637	202.35-203.75	EFS	PIF-3	18.0	1	19.37	16.29	12.97	14.77	18.46
		EFS	PIF-4	18.0	1	18.82	16.24	12.46	14.47	18.88
B1657	192.95-194.45	EFS	PIF-5	16.4	1	16.66	11.60	10.15	11.93	16.31
		EFS	PIF-5	16.4	2	16.31	12.77	10.10	12.13	16.42
		EFS	PIF-6	16.4	1	16.87	12.22	10.96	12.52	16.57
		EFS	PIF-6	16.4	2	16.57	13.27	10.93	12.73	16.69
B1697	109.00-110.60	EFS	PIF-7	17.2	1	17.32	12.22	10.78	12.46	16.36
		EFS	PIF-7	17.2	2	16.36	13.13	10.74	12.63	16.45
		EFS	PIF-8	17.2	1	17.58	12.06	10.49	12.41	16.68
		EFS	PIF-8	17.2	2	16.68	13.03	10.45	12.53	16.78

Table 6 (cont.) Summary of Deterioration Test Results

Boring	Depth (ft)	Material	Test No.	w_o %	Cycle No.	Equilibrium Water Content (%) RH (%)				
						96	87	56	87	96
BC1	206.70-207.60	EFS	PIF-9	17.5	1	18.19	13.65	12.34	13.97	18.21
		EFS	PIF-9	17.5	2	18.21	14.65	12.28	14.16	18.48
		EFS	PIF-10	17.5	1	18.35	12.59	11.14	12.99	18.58
		EFS	PIF-10	17.5	2	18.58	13.78	11.02	13.29	18.83
B1619	206.55-207.50	EFS	PIF-11	16.7	1	17.09	12.78	11.56	13.04	16.94
		EFS	PIF-11	16.7	2	16.94	13.79	11.49	13.24	16.97
		EFS	PIF-12	16.7	1	17.29	12.62	11.31	12.99	17.44
		EFS	PIF-12	16.7	2	17.44	13.80	11.37	13.22	17.65
B1617	203.90-204.90	EFS	PIF-13	17.7	1	18.35	13.54	12.09	13.72	17.96
		EFS	PIF-13	17.7	2	17.96	14.40	11.92	13.92	19.19
		EFS	PIF-14	17.7	1	18.62	13.83	12.47	14.15	18.65
		EFS	PIF-14	17.7	2	18.65	14.77	12.42	14.35	18.72
BF1A	162.40-163.50	EFS	PIF-15	17.3	1	17.66	12.82	11.31	13.10	17.54
		EFS	PIF-15	17.3	2	17.54	13.82	11.42	13.29	17.46
		EFS	PIF-16	17.3	1	18.15	12.94	11.44	13.23	18.18
		EFS	PIF-16	17.3	2	18.18	13.94	11.42	13.42	18.69

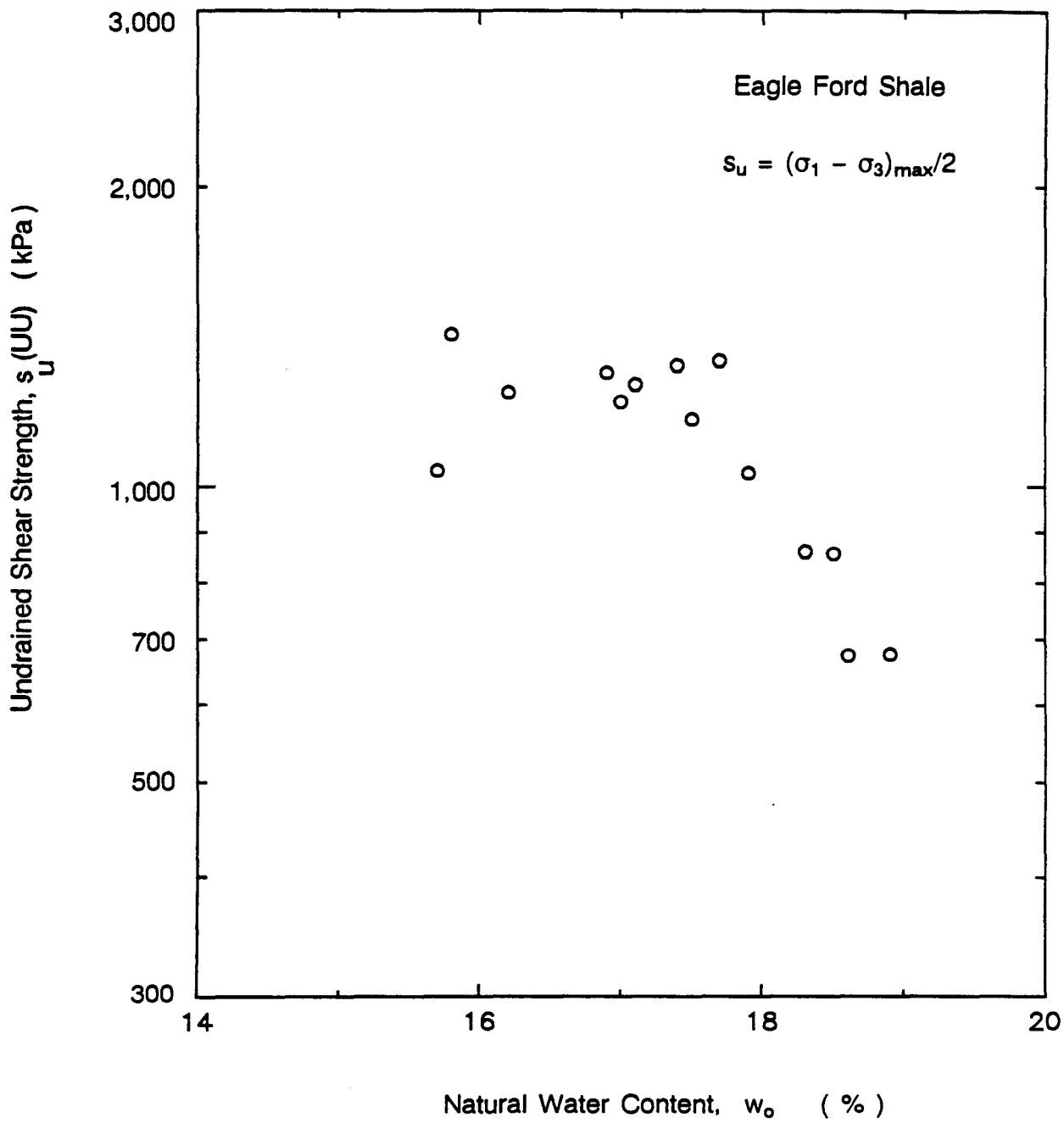


Fig. 1 Undrained Shear Strength, s_u(UU) vs Natural Water Content

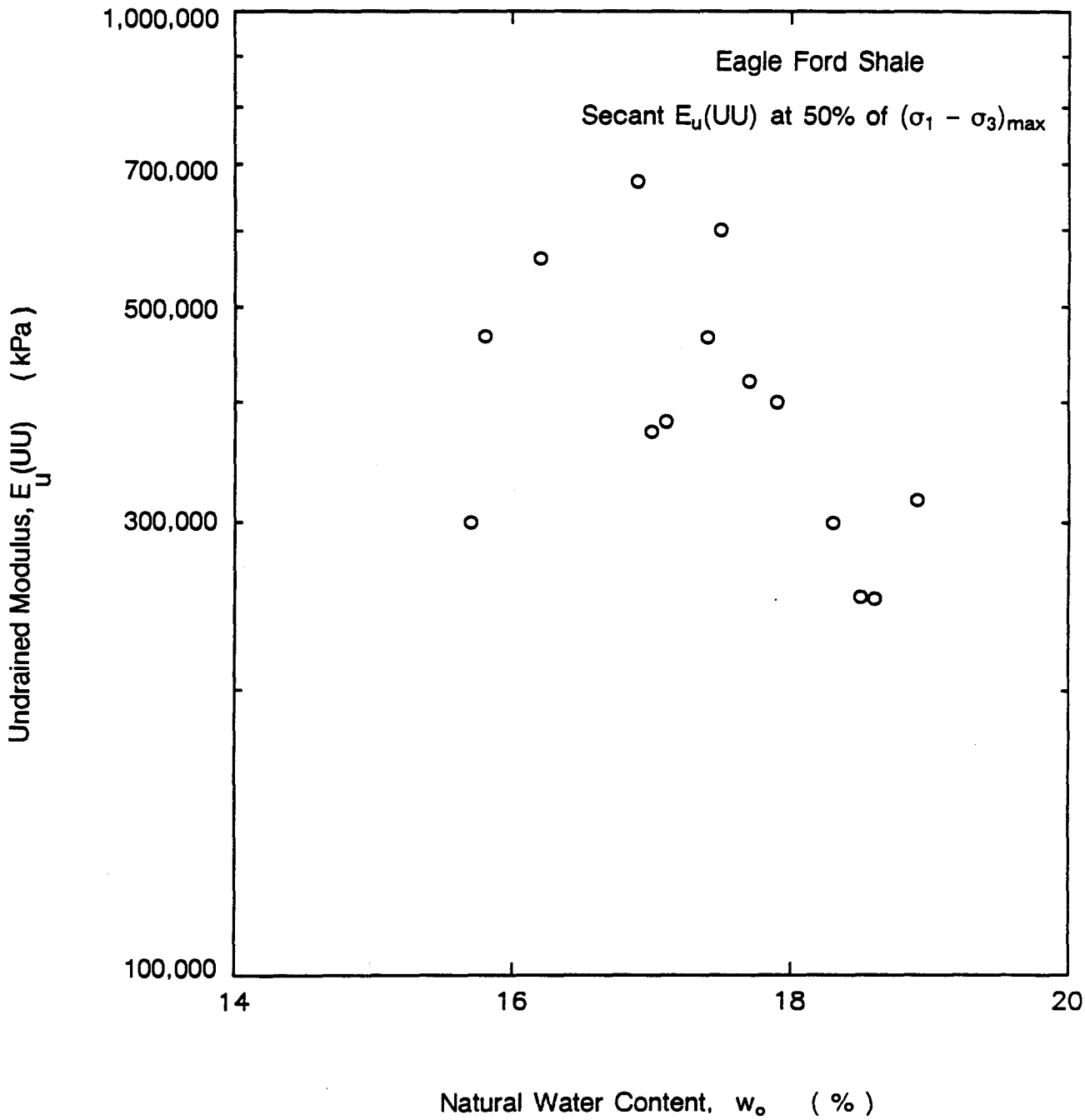


Fig. 2 Undrained Modulus, E_u (UU) vs Natural Water Content

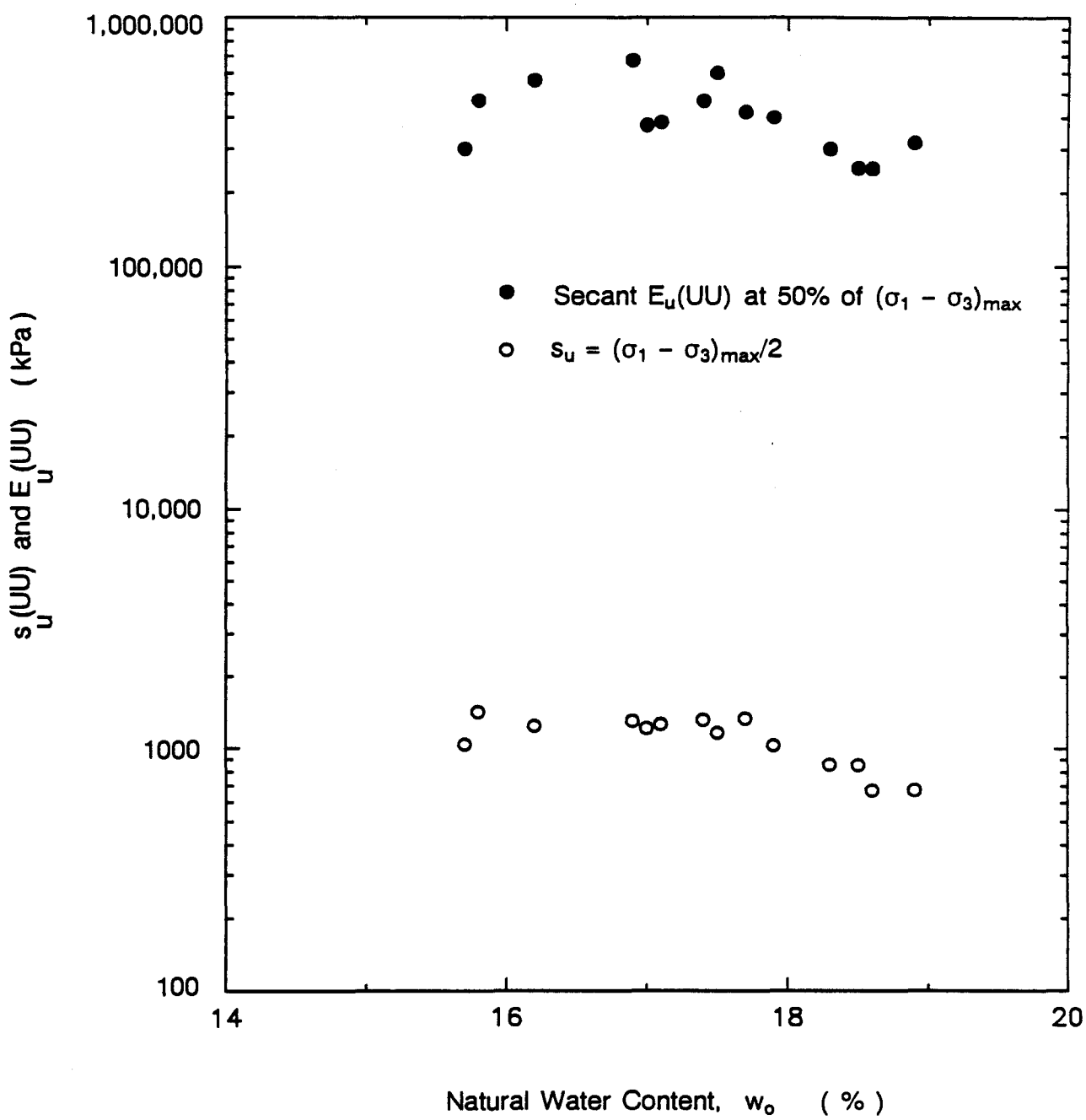


Fig. 3 $s_u(UU)$ and $E_u(UU)$ vs Natural Water Content

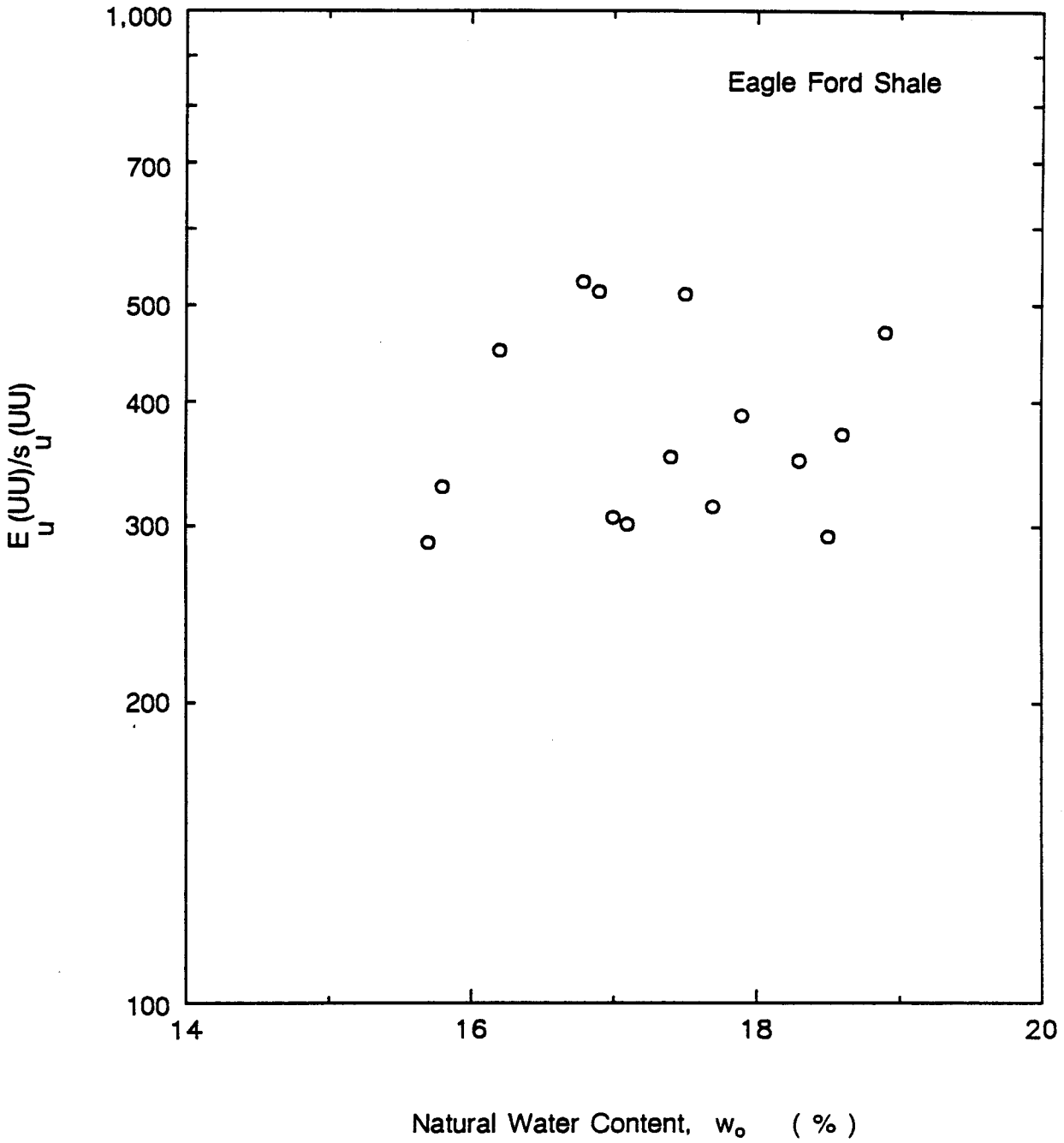


Fig. 4 $E_u(UU)/s_u(UU)$ vs Natural Water Content

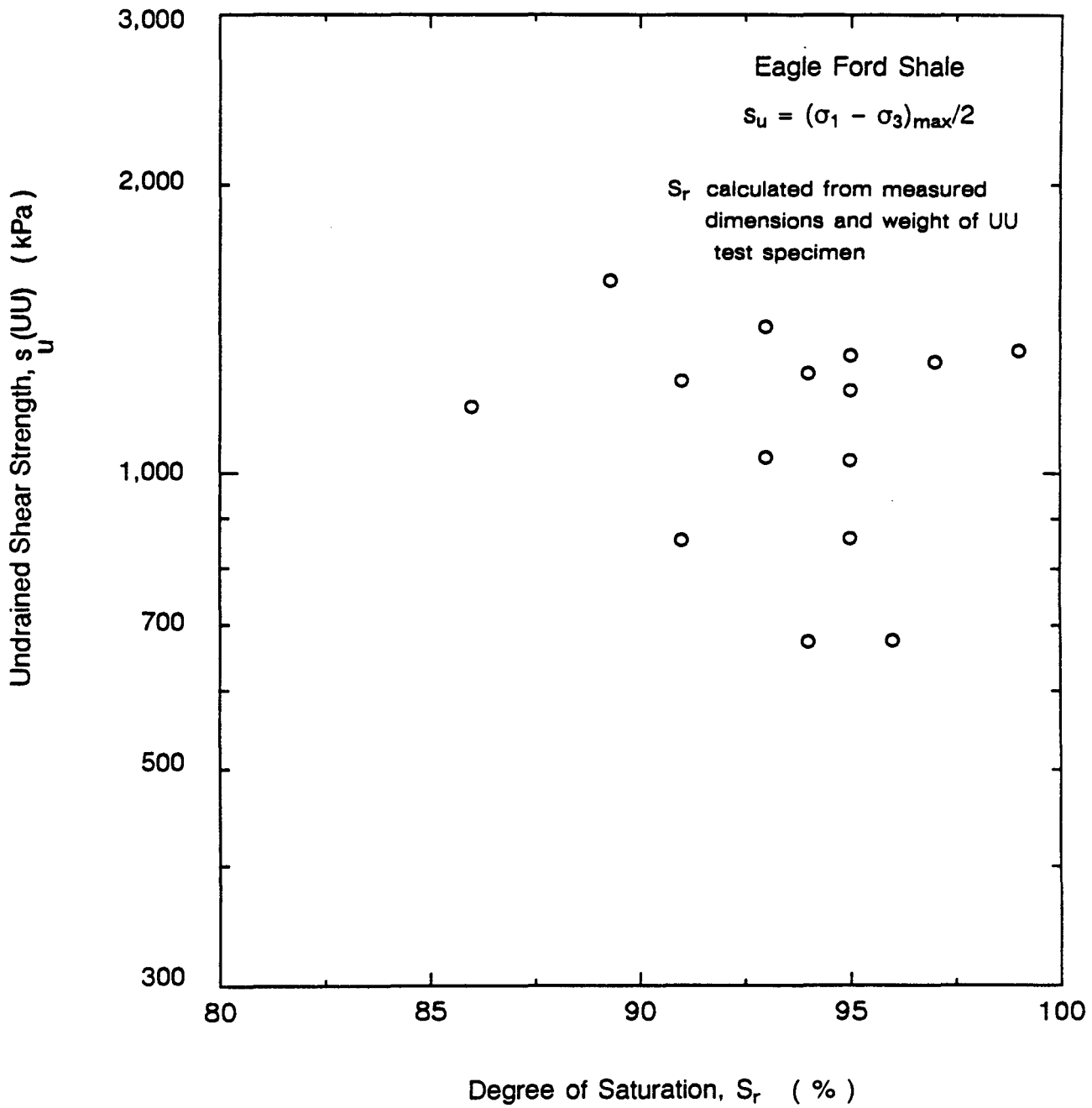


Fig. 5 Undrained Shear Strength, s_u(UU) vs Degree of Saturation

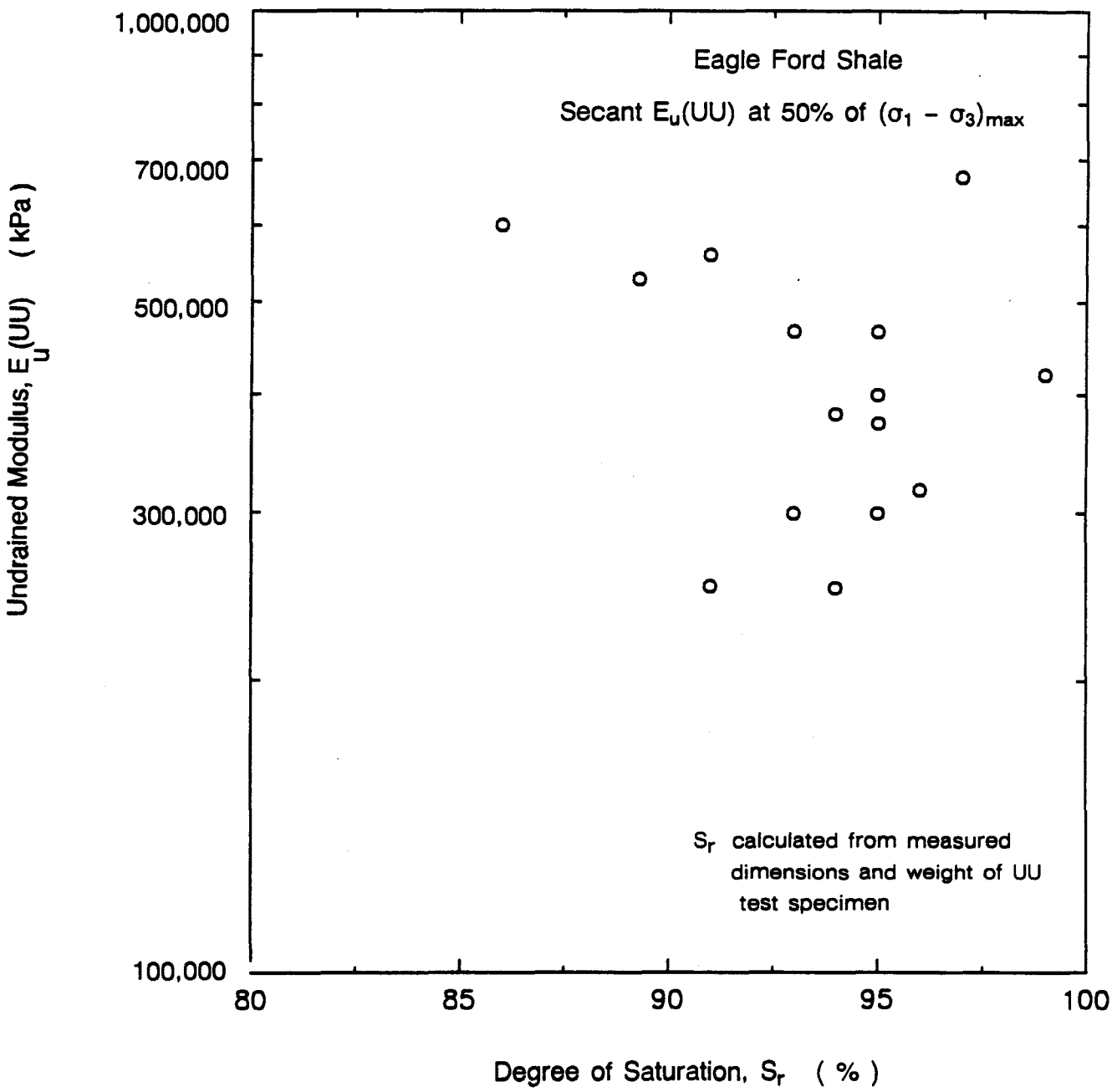


Fig. 6 Undrained Modulus, E_u (UU) vs Degree of Saturation

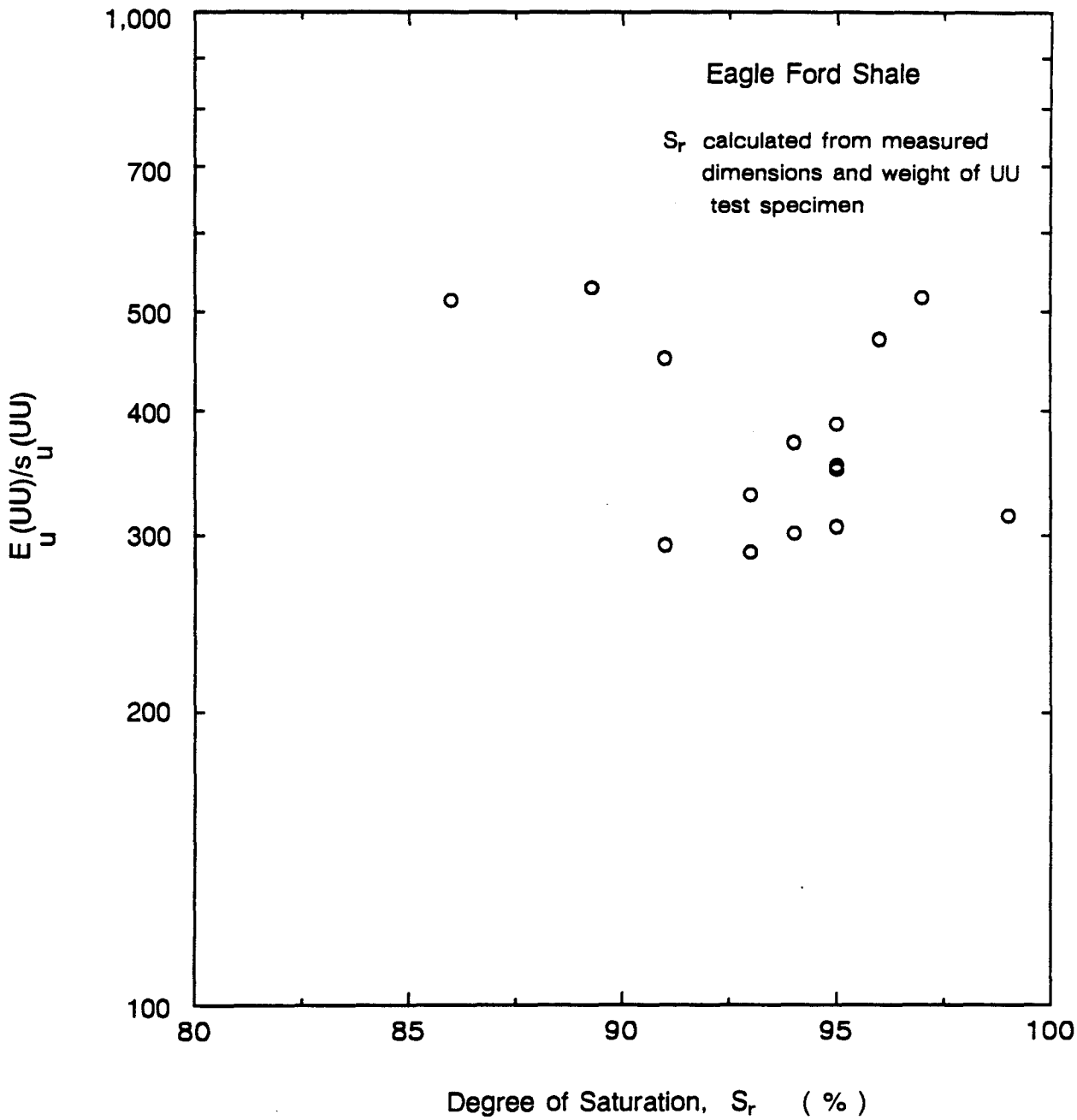


Fig. 7 $E_u(UU)/s_u(UU)$ vs Degree of Saturation

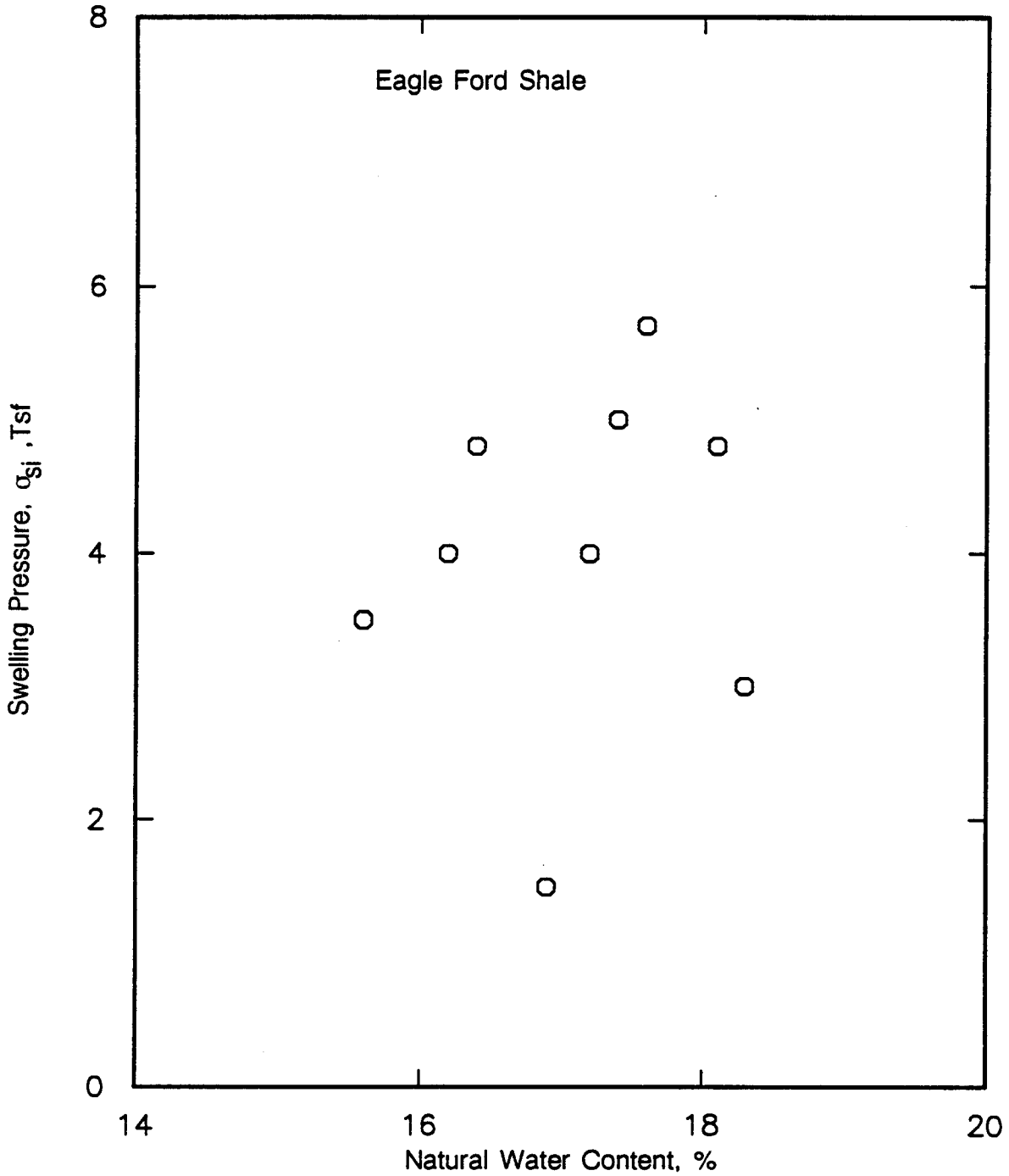


Fig. 8 Swelling pressure, σ_{si} vs Natural Water Content

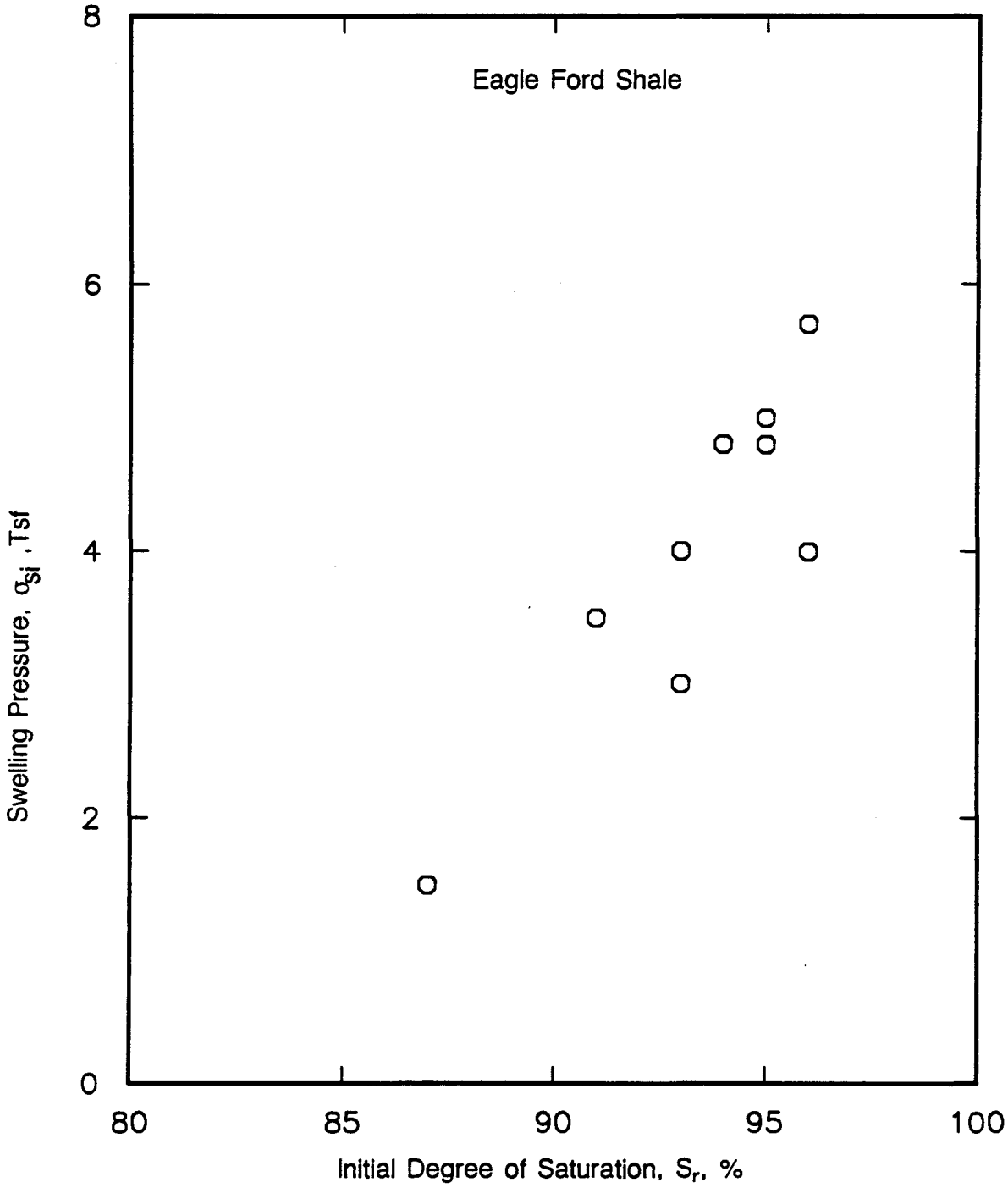


Fig. 9 Swelling Pressure, σ_{si} vs initial Degree of Saturation

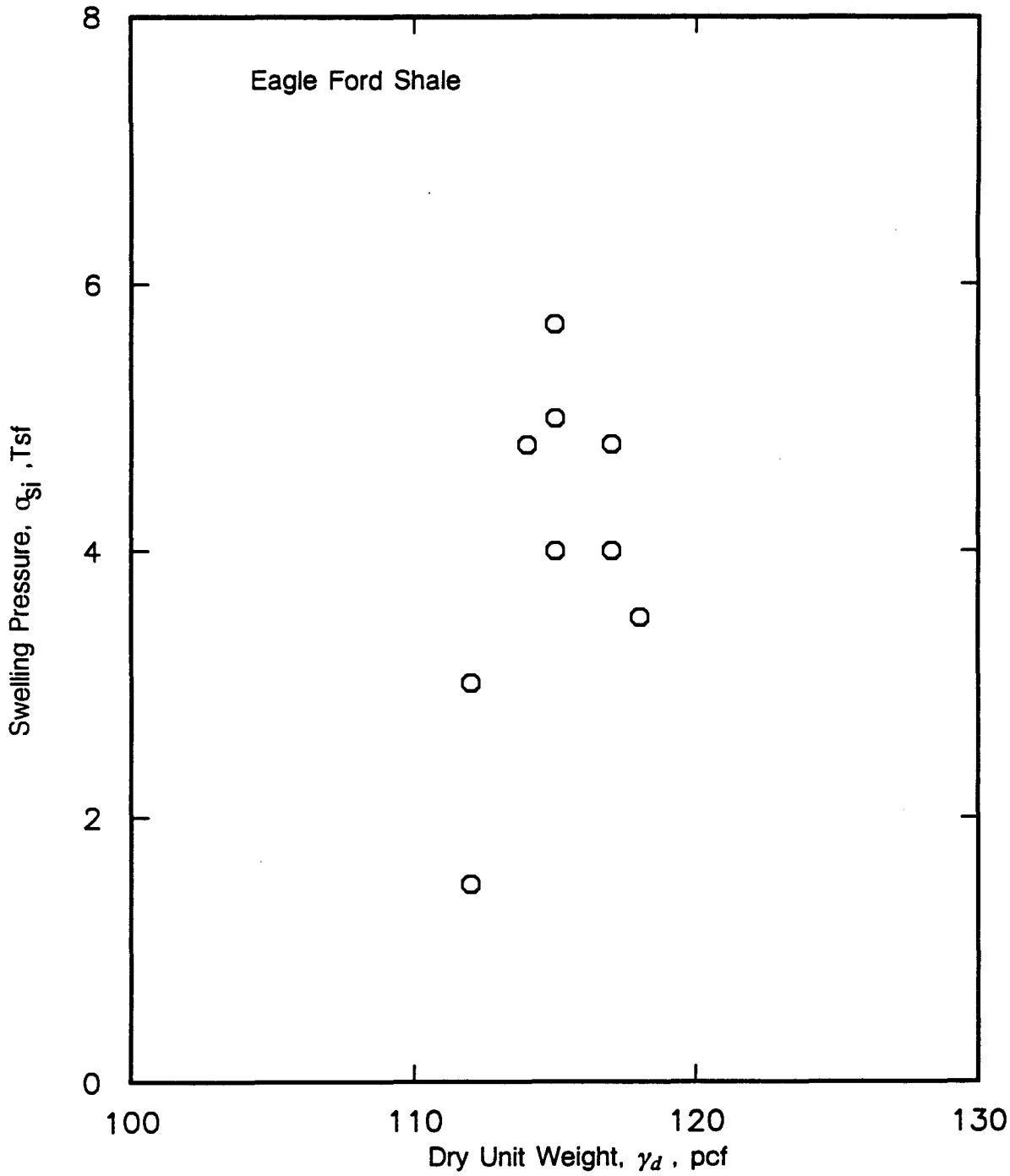


Fig. 10 Swelling Pressure, σ_{si} vs Dry Unit Weight

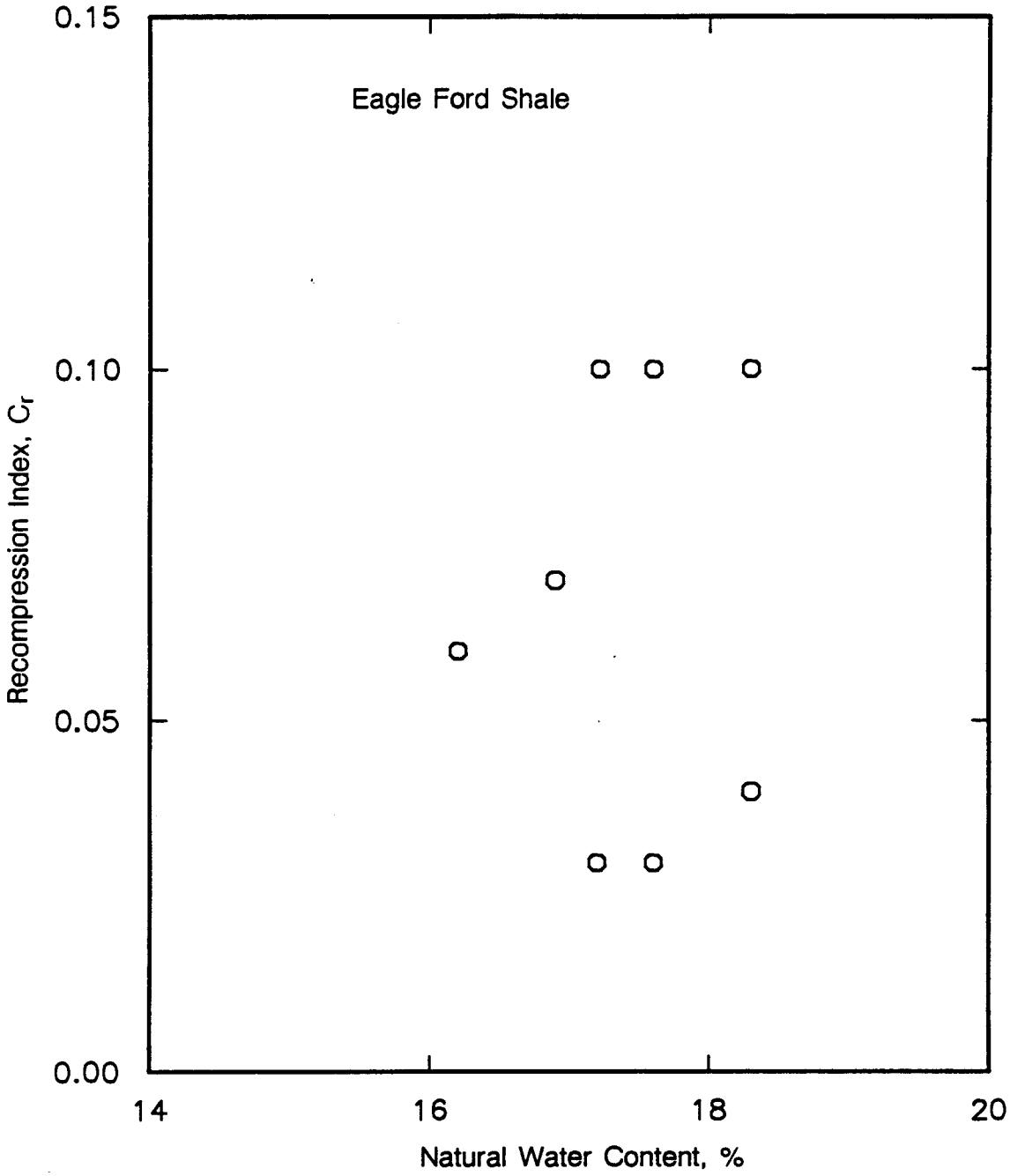


Fig. 11 Recompression Index, C_r vs Natural Water Content

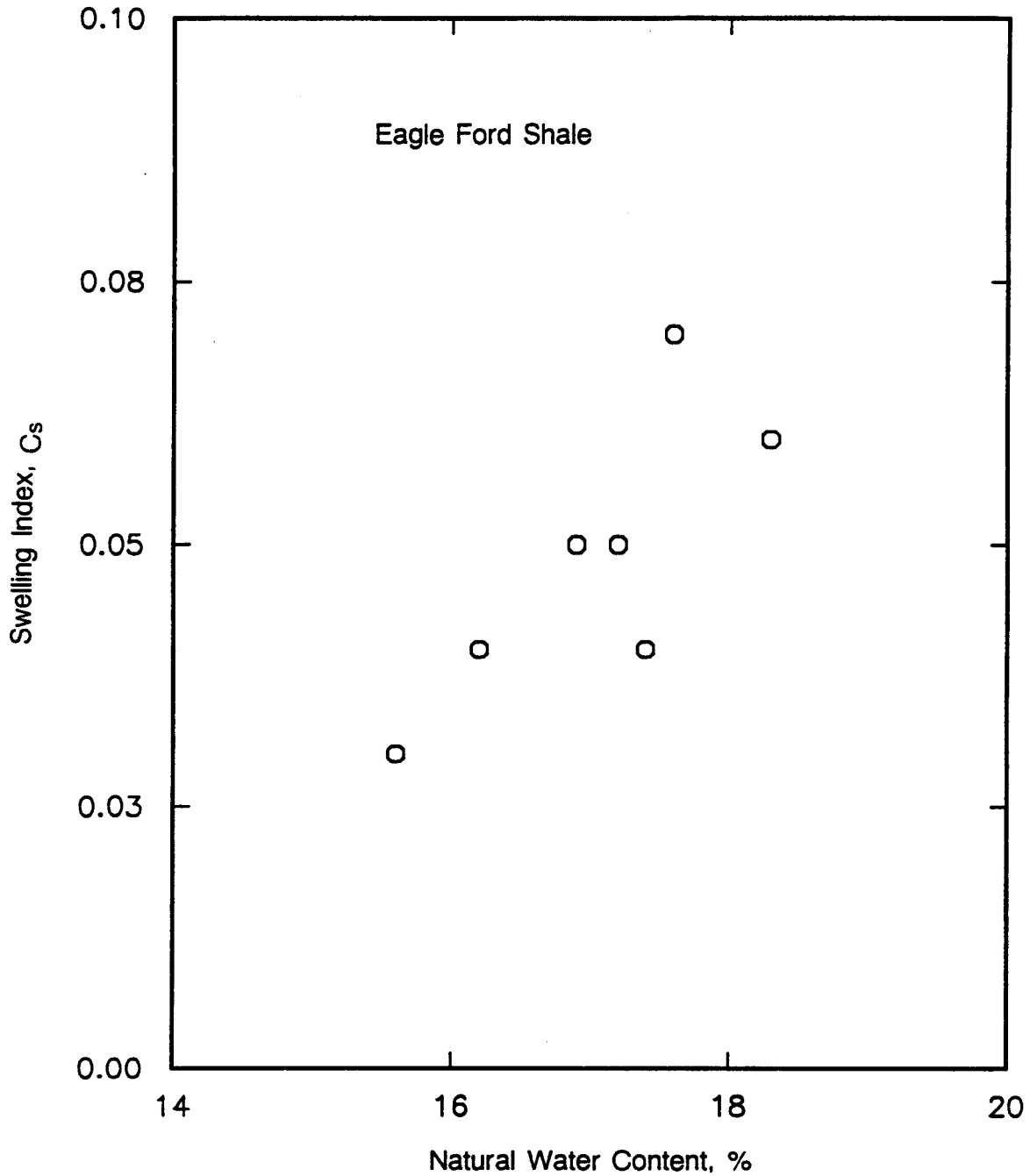


Fig. 12 Swelling Index, C_s vs Natural Water Content

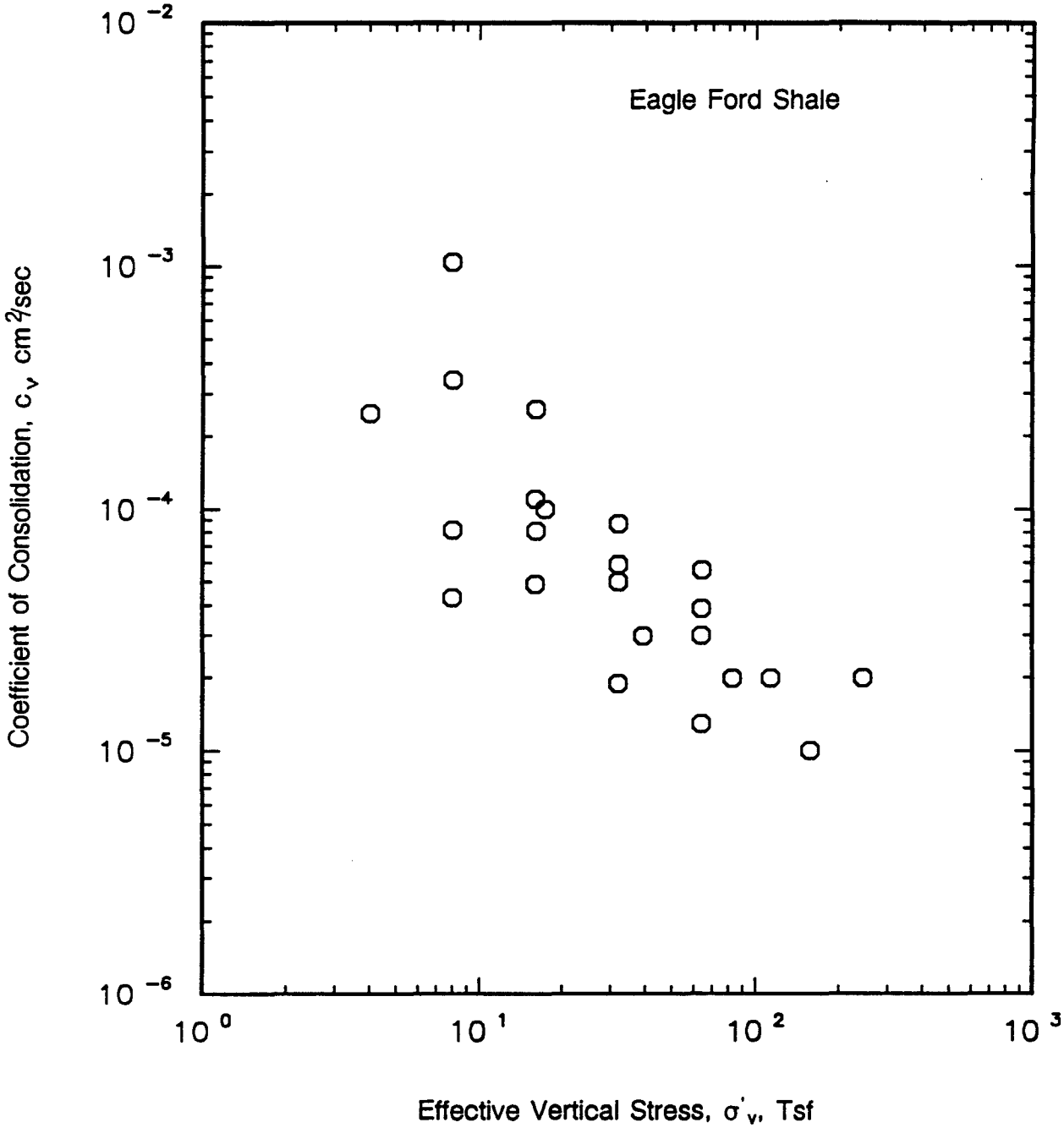


Fig. 13 Coefficient of Consolidation vs Effective Vertical Stress

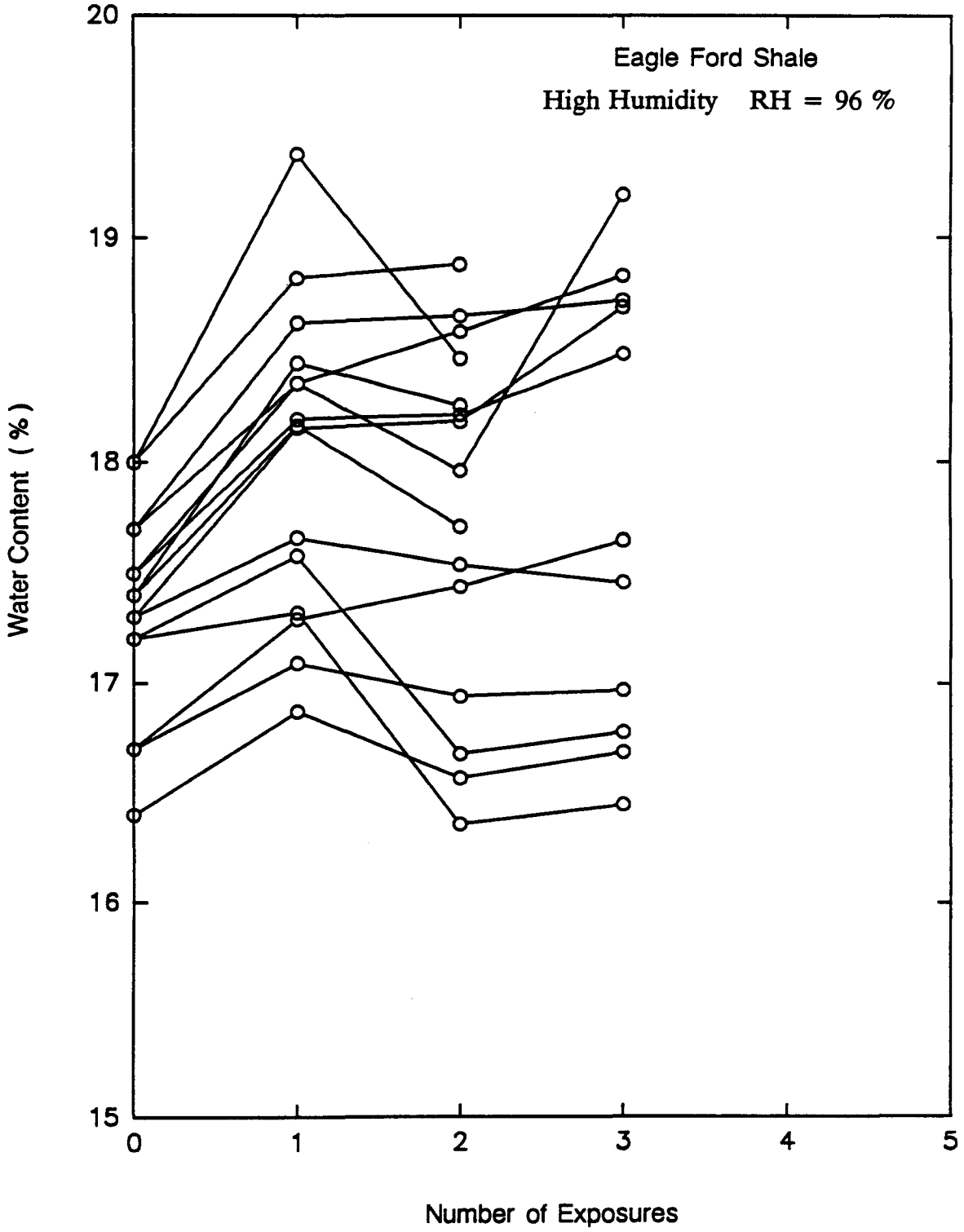


Fig. 14 Water Content vs Number of Environmental Exposures

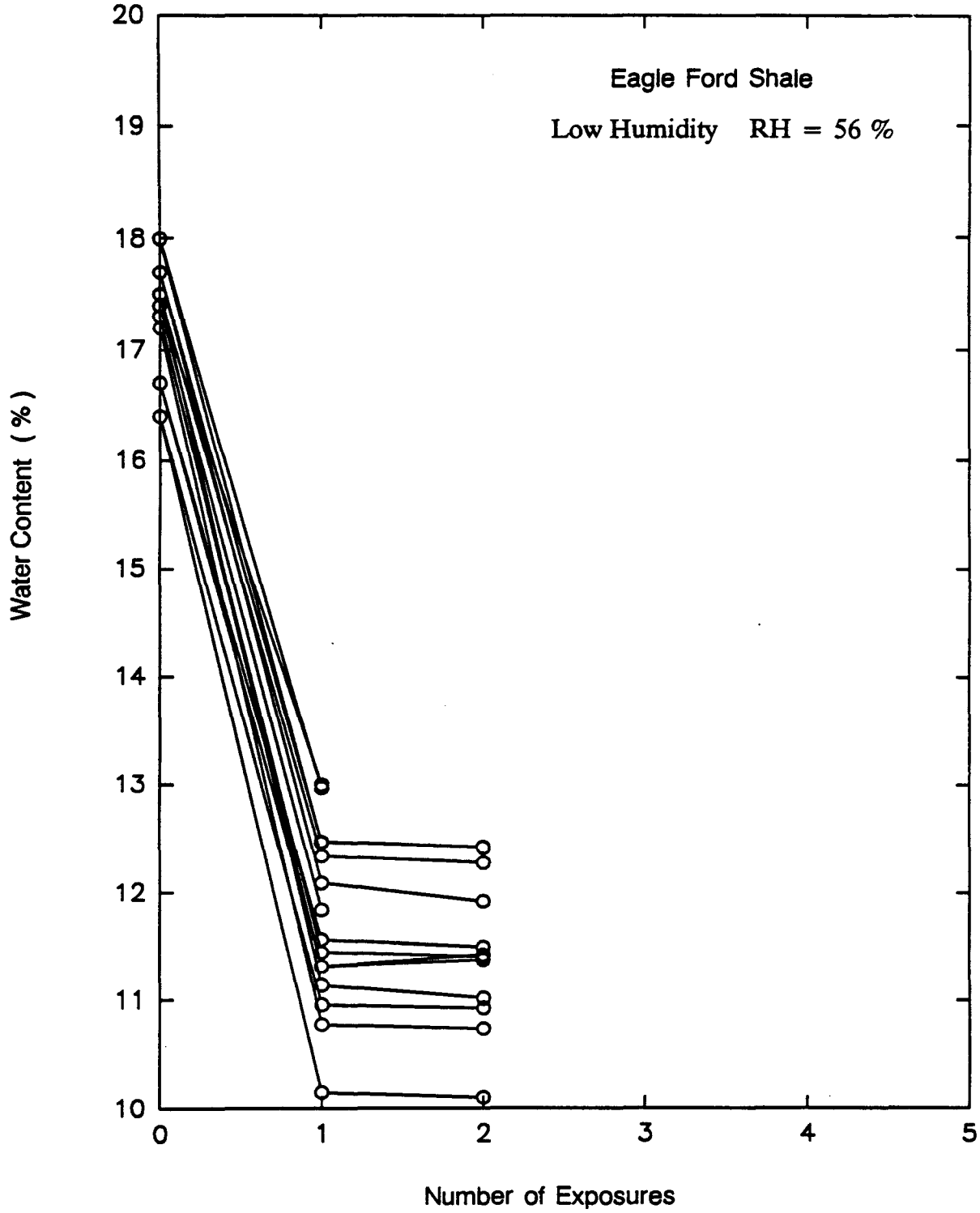


Fig. 15 Water Content vs Number of Environmental Exposures

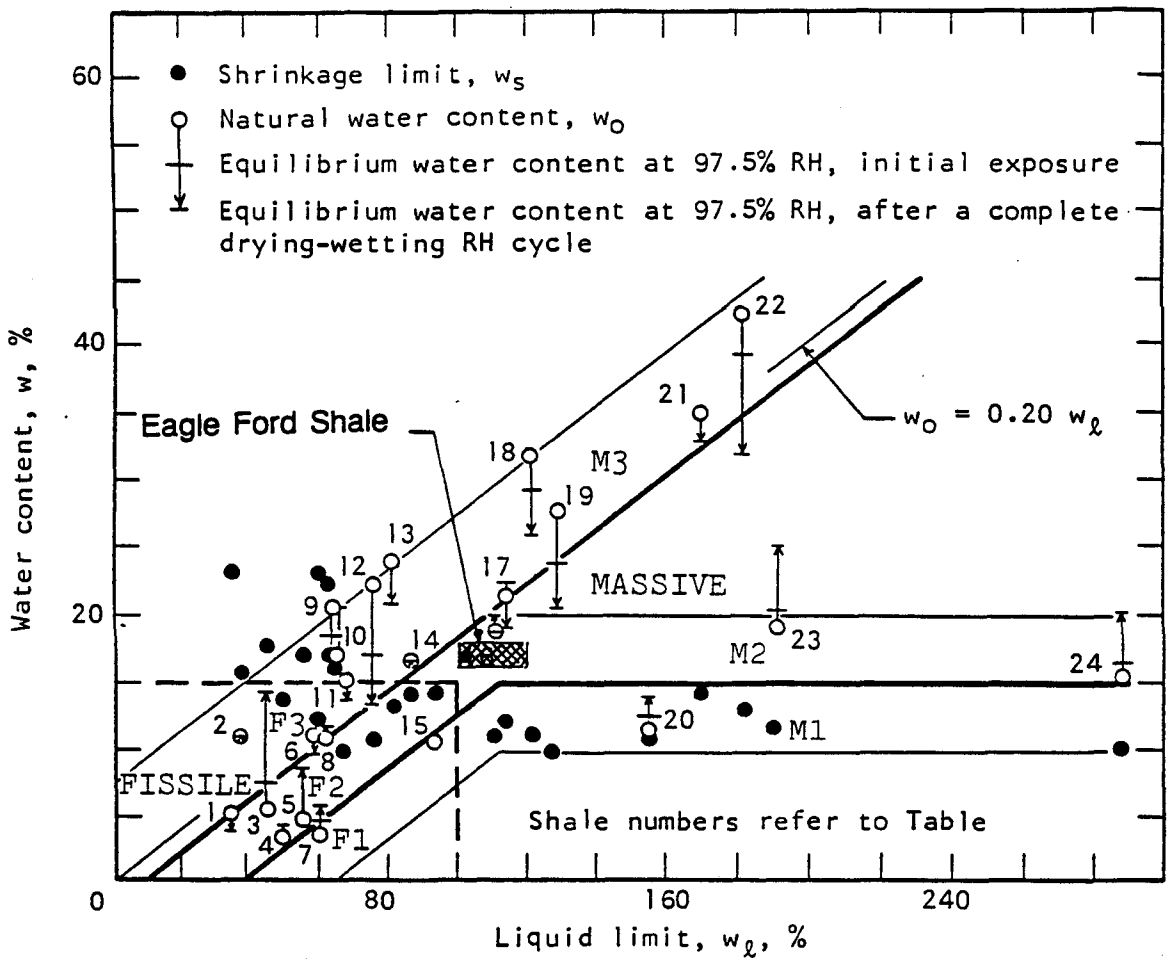


Fig. 16 Characterization of Shale Deterioration upon Environmental Exposure (after Mesri and Cepeda, 1990).

APPENDIX AI

Testing Procedure Development for Eagle Ford Shale, Taylor Marl, and Bentonite from the SSC Project

TESTING PROCEDURE DEVELOPMENT FOR EAGLE FORD SHALE, TAYLOR MARL, AND BENTONITE FROM THE SSC PROJECT

Introduction

This is the Procedure Development report for Consultant Agreement No. SP-3134 with The Earth Technology Corporation, Long Beach, California. Laboratory testing procedures have been developed for determining engineering properties of geologic materials present at the proposed site for the Superconducting Super Collider Project in Ellis County, Texas. Special procedure and equipment are described for laboratory testing of Eagle Ford shale, Taylor marl and Bentonite. The tests include unconsolidated undrained triaxial compression, drained direct shear, swelling pressure, recompression, compression and swell, environment controlled deterioration, Atterberg limits, water content, and carbonate content.

The laboratory work is being carried out under direct supervision of G. Mesri, by S. Ali and M. Pakbaz. Mr. Ali has had over 10 years of professional experience in laboratory and in situ testing of soils. Since 1985, he has been a graduate student at the University of Illinois. Mr. Ali is completing laboratory research for a Ph.D. Thesis on Engineering Properties of A Stiff Clay Overconsolidated by Desiccation. Mr. Pakbaz has been a graduate student at the University of Illinois since 1984. He is completing laboratory and analytical research for a Ph.D. thesis on Measurement and Field Application of Swelling Pressure of Shales. Laboratory work is also being done by Mr. L. Nojszewski who has a M.S. degree in Land Reclamation from Academy of Agriculture, Warsaw, Poland. He has participated in research on Construction of Embankments on Soft Ground, jointly carried

out by the Swedish Geotechnical Institute and Academy of Agriculture of Poland.

Mineralogical analysis of the shales are being carried out by Professor S. P. Altaner of the Department of Geology of the University of Illinois. Professor Altaner is an expert on clay mineralogy.

S. Ali and M. Pakbaz have contributed to the preparation of this report.

1. Unconsolidated Undrained Triaxial Compression Tests

Unconsolidated undrained triaxial compression (UU) tests are being carried out on the core samples of Eagle Ford shale and Taylor marl to determine undrained shear strength, s_u (UU) and undrained modulus, E_u (UU). The cores are on average 2 inches (50.8 mm) in diameter and specimens with L/D of 2 are being prepared. In case intact pieces of core of sufficient length are not available, shorter specimens (with L/D no less than 1.75) are being used.

The core is placed in a tight fitting mold and the top and bottom ends are carefully trimmed by a surgical knife. The two ends are finished flat by cutting with a very sharp stainless steel straight edge. All possible precautions are taken to avoid any drying of the specimen and the entire trimming operation is carried out inside a temperature and humidity controlled room (Temperature 15°C and Relative Humidity 95%). Several measurements of the diameter and height of the specimen are taken respectively with a micrometer and a dial gauge mounted on a flat block. After measuring the weight of the specimen it is mounted on the pedestal of the triaxial cell and sealed by 0.012 inch thick latex membrane and four O-rings at each end.

High pressure triaxial cells with capacity to test specimens under equal all-round pressures of up to 2000 psi (24 MPa) are being used. The specially designed cells have four drainage connections. Two for the top of the specimen and two for the bottom, thus allowing the top and bottom of the specimens to be flushed to remove any air trapped between the membrane and the specimen. The flushing of each end is done by applying suction to one

connection while deaired water is supplied through the other line. In order to ensure that the specimen does not get any chance to swell by imbibing water during the flushing operation, flushing is done after a confining pressure of 100 psi (690 kPa) is applied.

The axial load is measured with a load cell mounted at the end of the loading piston, immediately above the sample cap. The load measured by the load cell thus excludes any possible friction between the piston and the bushing. In addition to the load cell, the axial load is also being measured by a proving ring outside the pressure chamber. The axial deformation during the test is determined by measuring the relative movement between the loading piston and the top of the triaxial cell using dial indicators reading to 0.0001 inch. The specimens are being subjected to equal all-round confining pressures of 100, 200, and 400 psi (690, 1380 and 2760 kPa). The pressure of 100 psi (690 kPa) is being applied by Self Compensating Mercury Columns while 200 and 400 psi pressures (1380 and 2760 kPa) are being applied by a high pressure control panel using nitrogen bottles. The pressure is controlled by sensitive regulators that maintain the pressure constant (within ± 0.5% of applied pressure). The pressure from the control panel goes to the cell through a three phase transfer chamber, and thus distilled de-aired water is the cell fluid. The specimens are sheared using a 10 ton capacity compression machine. The axial deformation rate is selected to reach failure, $(\sigma_1 - \sigma_3)_{max}$, within a time, t_f, of 15 to 30 minutes. Data forms 1A and 1B are used for unconsolidated undrained triaxial compression test.

The procedure is similar to ASTM D1850-87 and ASTM D2664-86. The following step by step procedure highlights the significant items, specially

those considered to be important for the shales being tested for this project.

1. Select the core to be tested and note bore hole number, depth and other available information.

2. Carefully remove the sealing wax and make note of any sign of disturbance (softening or swelling), mechanical breaks, presence of fissures, calcite concretions, etc.

3. Place the core in a tight fitting mold and carefully trim the top and bottom of the core using a surgical knife.

4. Take two water content samples, one from the top and the other from the bottom of the specimen. Use chunks of shale weighing about 20 gms each and avoid thin flaky shavings which tend to lose moisture rapidly. Take the weight of the moisture content containers as soon as sufficient quantity of material, say 40 to 50 gms, is put in them.

5. Finish the two ends of the specimen flat, by cutting (shaving) with a very sharp stainless steel straight edge.

6. Carefully take the finished core out of the mold and make several measurements of the diameter by using a micrometer. Take several measurements of the height of the specimen by a dial gauge mounted on a flat block.

7. To prevent any loss of moisture from the specimen, perform steps 1 to 6 above, while inside the temperature and humidity controlled room (T = 15°C, RH = 96%).

8. Take the weight of the trimmed specimen using a balance capable of reading within 0.01 gm. From the measured dimensions and weight of the specimen, calculate total unit weight, γ. Using the results of water content measurements, calculate the dry unit weight, γ_d. Also calculate γ from water content and specific gravity of solids.

9. Mount the specimen on the triaxial cell pedestal with porous stones at the top and bottom. Use filter cloths (Tetko polyester screen HD 7-6) in between the specimen and the porous stones. Use double layers of filter cloths to reduce end restraint due to friction.

10. Grease the side of the top cap by a thin coat of high vacuum silicone grease and place the top cap on the specimen.

11. Place a 1/2 inch wide side strip around the porous stones to prevent puncturing of the membranes under high cell pressure.

12. Place a 0.012 inch thick latex membrane on the specimen and seal it with 4 o-rings at the pedestal end and another 4 o-rings around the top cap.

13. Connect the top drainage lines.

14. Fill the cell with deaired distilled water and raise the cell pressure to 100 psi (690 kPa).

15. Flush the top and bottom of the specimen. Flush each end by applying suction to one connection while supplying deaired distilled water through the other line to avoid any swelling.

16. Increase cell pressure to desired pressure of 200 or 400 psi. Allow about 15 minutes for the specimen to equilibrate under the applied cell pressure.

17. Set the platen travel rate of the compression machine such that the specimen fails in about 15 to 30 minutes. Select platen travel rate based on the expected axial strain at failure and the compression of the proving ring.

18. Bring the loading piston in contact with the specimen loading cap. Set the axial deformation dial and record the proving ring dial and the load cell indicator reading at the contact.

19. Turn on the compression machine and take readings of axial deformation dial and the corresponding proving ring dial and load cell readings at close intervals in the beginning of the test. Note the time to failure.

20. Stop the test when the rate of drop in the post peak load becomes small.

21. Reduce the cell pressure to 100 psi. Apply suction to the top and bottom drainage connections and remove the water from the drainage lines.

22. Remove the cell from the compression machine and drain out the water from the cell.

23. Remove the membrane and make a sketch of the failed specimen.

24. Weigh the failed specimen. Compare this weight to the initial weight of the specimen.

25. Take three water content samples from the failed specimen. Use chunks of about 50 gm for each water content determination. Do not oven-dry the entire specimen, use the remainder of the specimen for other tests.

GEOTECHNICAL ENGINEERING LABORATORY, UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

UNCONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION (UU) TEST

PROJECT	BORING	MATERIAL

TEST NO.	SPECIMEN DIMENSIONS	WEIGHT
	HT., IN _____ DIA., IN _____ VOL. , IN^3 _____	GMS _____

INSITU EFF. VER. STRESS	CELL PRESSURE SEQUENCE	TECHNICIAN _____
LB/IN^2 _____	LB/IN^2 _____	COMPUTED _____
		CHECKED _____

LIQIUID LIMIT	PLASTIC LIMIT	TOTAL UNIT WEIGHT	DRY UNIT WEIGHT	DATE

WATER CONTENT DATA (ALL WEIGHTS IN GRAMS)

SET-UP

POSITION						AVERAGE WATER CONTENT %
CONTAINER NO.						
WT WET SOIL + CONTAINER						
WT DRY SOIL + CONTAINER						
WT WATER						
WT CONTAINER						
WT DRY SOIL						
WATER CONTENT, %						

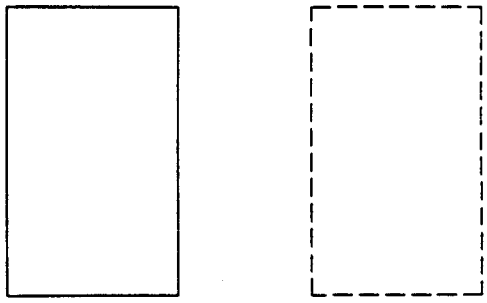
TEAR-DOWN

POSITION						AVERAGE WATER CONTENT %
CONTAINER NO.						
WT WET SOIL + CONTAINER						
WT DRY SOIL + CONTAINER						
WT WATER						
WT CONTAINER						
WT DRY SOIL						
WATER CONTENT, %						

SPECIMEN WEIGHT

	INITIAL	FINAL
SOIL + TARE		
TARE		
SOIL		

SPECIMEN SHAPE



BEFORE AFTER

FORM 1A

GEOTECHNICAL ENGINEERING LABORATORY, UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

UNCONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION (UU) TEST			DATE
PROJECT	BORING		MATERIAL
TEST NO.	SPECIMEN DIMENSIONS HEIGHT, IN _____ AREA, IN² _____		TECHNICIAN _____ COMPUTED _____ CHECKED _____
PROVING RING CONSTANT LB/DIV _____ P. R. NO. _____	AXIAL DEFORMATION DIAL CONSTANT IN/DIV _____		LOAD CELL CONSTANT LB/DIV _____ L. C. NO. _____
CELL NO.	CELL PRESSURE PSI _____	PLATEN TRAVEL RATE IN/MIN _____	TIME TO FAILURE MINS _____

TIME	AXIAL DIAL READING	AXIAL STRAIN %	AREA IN²	PROVING RING READING	P. R. LOAD LBS	P. R. $\sigma_1 - \sigma_3$ LB/IN²	LOAD CELL READING	L. C. LOAD LBS	L. C. $\sigma_1 - \sigma_3$ LBS/IN²

SUPERCONDUCTING SUPER COLLIDER PROJECT, WAXAHACHIE, TEXAS

UNCONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION (UU) TEST

PROJECT	BORING	MATERIAL

TEST NO.	SPECIMEN DIMENSIONS	WEIGHT
	HT., IN _____ DIA., IN _____ VOL. , IN^3 _____	GMS _____

INSITU EFF. VER. STRESS	CELL PRESSURE SEQUENCE	TECHNICIAN _____
LB/IN^2 _____	LB/IN^2 _____	COMPUTED _____
		CHECKED _____

LIQIUID LIMIT	PLASTIC LIMIT	TOTAL UNIT WEIGHT	DRY UNIT WEIGHT	DATE

WATER CONTENT DATA (ALL WEIGHTS IN GRAMS)

SET-UP

POSITION						AVERAGE WATER CONTENT %
CONTAINER NO.						
WT WET SOIL + CONTAINER						
WT DRY SOIL + CONTAINER						
WT WATER						
WT CONTAINER						
WT DRY SOIL						
WATER CONTENT, %						

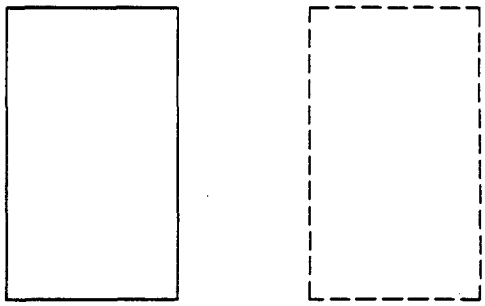
TEAR-DOWN

POSITION						AVERAGE WATER CONTENT %
CONTAINER NO.						
WT WET SOIL + CONTAINER						
WT DRY SOIL + CONTAINER						
WT WATER						
WT CONTAINER						
WT DRY SOIL						
WATER CONTENT, %						

SPECIMEN WEIGHT

SOIL + TARE	INITIAL	FINAL
TARE		
SOIL		

SPECIMEN SHAPE



BEFORE AFTER

FORM 1A

SUPERCONDUCTING SUPER COLLIDER PROJECT, WAXAHACHIE, TEXAS

UNCONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION (UU) TEST			DATE
PROJECT	BORING		MATERIAL
TEST NO.	SPECIMEN DIMENSIONS HEIGHT, IN _____ AREA, IN² _____		TECHNICIAN _____ COMPUTED _____ CHECKED _____
PROVING RING CONSTANT LB/DIV _____ P. R. NO. _____	AXIAL DEFORMATION DIAL CONSTANT IN/DIV _____		LOAD CELL CONSTANT LB/DIV _____ L. C. NO. _____
CELL NO.	CELL PRESSURE PSI _____	PLATEN TRAVEL RATE IN/MIN _____	TIME TO FAILURE MINS _____

TIME	AXIAL DIAL READING	AXIAL STRAIN %	AREA IN²	PROVING RING READING	P. R. LOAD LBS	P. R. $\sigma_1 - \sigma_3$ LB/IN²	LOAD CELL READING	L. C. LOAD LBS	L. C. $\sigma_1 - \sigma_3$ LBS/IN²

2. Drained Direct Shear Tests

Drained reversal direct shear tests on pre-cut specimens are being used to determine the residual friction angle, ϕ'_r, of the Eagle Ford Shale and Taylor Marl. Residual condition corresponds to the orientation of the plate-shaped particles along the shear plane. The shale is air-dried and then ball milled until all of a representative sample passes the No. 200 sieve. It is recognized that air drying of shale, especially if organic matter or clay minerals such as halloysite are present, can cause irreversible dehydration. However, this factor is not considered to be important for the shales in this project. The pulverized shale is being thoroughly rehydrated using tempering time of at least 1 week. The two halves of the reconstituted precut specimens are separately consolidated from a water content near liquidity index of 1.5, inside the top and bottom halves of the shear box. Each face of the shear surface is consolidated against a Tetko polyester screen (HD 7-6) supported by a smooth flat teflon plate. After consolidation, the two smooth and flat surfaces are assembled together and sheared against each other. The samples are consolidated under a normal pressure of 100 psi (690 kPa). Some samples are subjected to drained reversal shear under 100 psi (690 kPa) while others are rebounded to 50 psi (345 kPa) and then assembled and sheared. Few selected samples will be consolidated to a normal pressure of 400 psi (2760 kPa) and then unloaded to 100 psi (690 kPa) and assembled and sheared. A shear displacement rate of 5×10^{-4} mm/min is being used. In general, the residual shear condition is expected to be reached after 50 mm of cumulative shear displacement. Data forms 2A and 2B are used for drained reversal direct shear test on pre-cut samples.

The procedure is similar to ASTM D3080-72, but differs in significant details for the shales being tested.

1. Select about 150 gms of air-dried sample. Ball-mill the sample until all the sample passes through the No. 200 sieve.

2. Add distilled water to the sample to reach a water content of about 150% (i.e. liquidity index of about 1.5). Allow the sample to rehydrate allowing a tempering time of at least 1 week.

3. Assemble the bottom half of the shear box covered by a filter cloth (Tetko Polyester Screen, HD 7-6) on a smooth teflon plate resting on the base of the reservoir (Fig. 1). Place the bottom half of the shear box upside down.

4. Similar to step 3, assemble the top half of the shear box, placing the right side up (i.e. bottom of the top half of the shear box resting on the teflon plate).

5. Carefully spoon the remolded shale sample inside the two halves of the shear box, making sure all the corners are completely filled up and no air bubbles are trapped. Fill each half to a thickness of about 3/4 inch (20 mm) so that the thickness of sample in each half after consolidation is no less than about 1/4 inch (6 mm). Smoothen the top surface, place a filter cloth, porous stone and loading cap.

6. Place the two halves of the shear box on two consolidation frames and consolidate them to the desired vertical pressure. To avoid any extrusion of sample, use small load increments in the beginning (say load increment ratio of 0.25). Under the final load, record time-settlement readings and plot compression against log time. Maintain the final load to complete primary consolidation and about half log time cycle of secondary compression.

7. Remove the two halves of the shear box from the consolidation frames. Place an adjustable spacer disk at the bottom of the lower half of the shear box to maintain the flat smooth surface of the prepared sample level with the top of the bottom half of the shear box.

8. Assemble the top and bottom halves of the shear box together, thereby placing the two smooth and flat surfaces one on top of the other and forming the reconstituted pre-cut specimen for the drained reversal direct shear test.

9. Place assembled shear box in the carriage and reapply the vertical load. Fill up the reservoir in the carriage with distilled water to prevent drying of the sample during the shear test.

10. Attach dial gages to measure vertical deformation and shear displacement.

11. Shear the sample with a shearing rate of 2×10^{-5} in/min to 5×10^{-5} in/min taking readings of the shear force proving ring, vertical deformation and shear displacement dials. After a shearing displacement of 0.2 inch in one direction, reverse the direction of shearing. At the beginning of each reversal of direction, ensure positive contact with the proving ring by turning the fine feed hand wheel.

12. Continue reversal shearing until a cumulative shear displacement of about 2 inches (50 mm) is reached or until the shearing resistance has leveled off and additional shearing is not resulting in any drop in the shearing resistance.

13. Remove the sample from the shear box. Carefully separate the two halves of the sample to observe the appearance of the shearing plane.

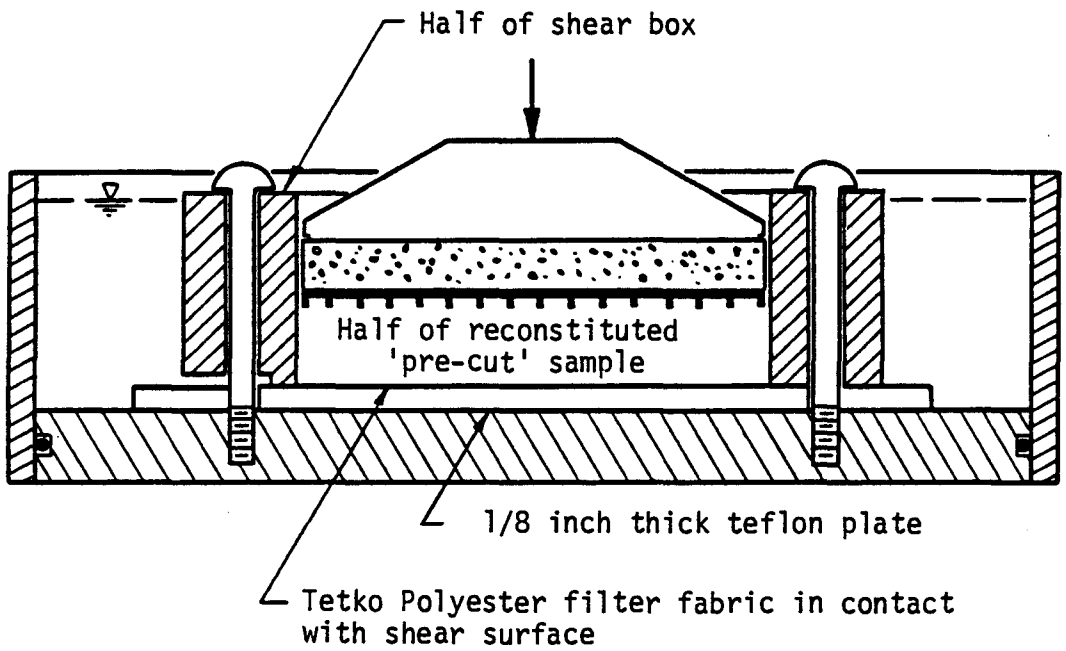


Fig. 1 Consolidation of 'pre-cut' shear surface for direct shear test.

GEOTECHNICAL ENGINEERING LABORATORY, UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

DRAINED REVERSAL DIRECT SHEAR TEST			DATE
PROJECT	BORING		MATERIAL
TEST NO.	SPECIMEN DIMENSIONS HT., IN _____ X-SEC. _____ AREA, IN^2 _____		TECHNICIAN ____ COMPUTED ____ CHECKED ____
LIQUID LIMIT	WATER CONTENT	REMOLDING WATER CONTENT	
VERTICAL PRESS. LB/IN^2 _____	DIRECT SHEAR DEVICE NO.	SHEARING RATE IN/MIN _____	
VER. DISP. DIAL CONST. IN/DIV _____	HOR. DEFOR. DIAL CONST. IN/DIV _____	PROVING RING CONSTANT LB/DIV _____	PROVING RING SL. NO. _____
SHEARING CYCLE NO.	CUMULATIVE SHEAR DISPLACEMENT BEGINNING, IN _____ END, IN _____	CUMULATIVE VER. DEFORMATION BEGINNING, IN _____ END, IN _____	

TIME	DISP. DIAL. READING	TOTAL DISP.	SHEAR DISP. IN	P. R. DIAL READING	CORR. P. R. READING	SHEAR FORCE LB	SHEAR STRESS LB/IN^2	VER. DIAL READING	VER. DEFOR. IN	REMARKS

FORM 2A

GEOTECHNICAL ENGINEERING LABORATORY, UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

ONE-DIMENSIONAL CONSOLIDATION TEST

PROJECT	BORING	MATERIAL

TEST NO.	TECHNICIAN _____ COMPUTED _____ CHECKED _____

LOAD NUMBER	LOAD NUMBER
TOTAL WEIGHTS	TOTAL WEIGHTS
PRESSURE	PRESSURE
DATE	DATE

CLOCK TIME	ELAPSED TIME mins	DIAL READING	TOTAL DEFORMATION
	0		
	0.10		
	0.25		
	0.5		
	1.0		
	2		
	4		
	8		

CLOCK TIME	ELAPSED TIME mins	DIAL READING	TOTAL DEFORMATION
	0		
	0.10		
	0.25		
	0.5		
	1.0		
	2		
	4		
	8		

FORM 2B

SUPERCONDUCTING SUPER COLLIDER PROJECT, WAXAHACHIE, TEXAS

DRAINED REVERSAL DIRECT SHEAR TEST			DATE
PROJECT SSC	BORING		MATERIAL
TEST NO.	SPECIMEN DIMENSIONS HT., IN _____ X-SEC. _____ AREA, IN² _____		TECHNICIAN ____ COMPUTED ____ CHECKED ____
LIQUID LIMIT	WATER CONTENT	REMOLDING WATER CONTENT	
VERTICAL PRESS. LB/IN² _____	DIRECT SHEAR DEVICE NO.	SHEARING RATE IN/MIN _____	
VER. DISP. DIAL CONST. IN/DIV _____	HOR. DEFOR. DIAL CONST. IN/DIV _____	PROVING RING CONSTANT LB/DIV _____	PROVING RING SL. NO. _____
SHEARING CYCLE NO.	CUMULATIVE SHEAR DISPLACEMENT BEGINNING, IN _____ END, IN _____	CUMULATIVE VER. DEFORMATION BEGINNING, IN _____ END, IN _____	

TIME	DISP. DIAL. READING	TOTAL DISP.	SHEAR DISP. IN	P. R. DIAL READING	CORR. P. R. READING	SHEAR FORCE LB	SHEAR STRESS LB/IN²	VER. DIAL READING	VER. DEFOR. IN	REMARKS

FORM 2A

SUPERCONDUCTING SUPER COLLIDER PROJECT, WAXAHACHIE, TEXAS

ONE-DIMENSIONAL CONSOLIDATION TEST

PROJECT SSC	BORING	MATERIAL
TEST NO.	TECHNICIAN _____ COMPUTED _____ CHECKED _____	

LOAD NUMBER		LOAD NUMBER	
TOTAL WEIGHTS		TOTAL WEIGHTS	
PRESSURE		PRESSURE	
DATE		DATE	

CLOCK TIME	ELAPSED TIME mins	DIAL READING	TOTAL DEFORMATION
	0		
	0.10		
	0.25		
	0.5		
	1.0		
	2		
	4		
	8		

CLOCK TIME	ELAPSED TIME mins	DIAL READING	TOTAL DEFORMATION
	0		
	0.10		
	0.25		
	0.5		
	1.0		
	2		
	4		
	8		

FORM 2B

3. Swelling Pressure Tests

Intact specimens of Eagle Ford shale or Taylor marl are trimmed into a 1.77 inch (45 mm) inside diameter confining ring coated with a thin film of high vacuum silicone grease. The trimming is done with the help of the sharp cutting edge of the confining ring and a very sharp and pointed stainless steel surgical blade (Bard Parker No. 10). The top and bottom of the 0.45 inch (11.43 mm) thick specimen are trimmed by the surgical blade and finished flat using a very sharp stainless steel straight edge. The trimming operation is carried out inside of a temperature and humidity controlled room (Temperature 15°C and Relative Humidity 95%).

The specimen enclosed by the confining ring is set up on a porous stone inside the consolidation cell, and is loaded from the top by a porous stone attached to a loading cap. The shale surfaces at the top and bottom are separated from the porous stones by a layer of Tetko Polyester Screen (DH-7-6). The specimen is mounted either in a Wykeham-Farrance lever arm-weight loading frame or in a rigid frame with a load cell. The axial deformation dial is zeroed under a seating load of 1/16 to 1/3 tsf and then distilled water is added into the consolidation cell. In the Wykeham-Farrance frames load increments are applied in order to prevent swelling of the specimen. For this purpose an axial compression equal to a previously measured machine deflection is allowed under each pressure increment. The process is continued until at least the end-of-primary swelling pressure is reached. In the rigid frame system, as soon as water is added the axial load cell begins to measure the increase in swelling pressure with time. A screw control is used to incrementally compensate for a previously calibrated

machine deflection so that the specimen remains at constant void ratio throughout the test.

For the tests mounted on Wykeham-Farrance loading system, after reaching the constant volume swelling pressure, the relationship between swelling pressure and swelling strain is measured using either load- or deformation-controlled unloading. In the load-controlled tests, decrements of load are removed and primary swelling is measured with time. After the completion of the primary swelling, the process of unloading is continued. In the deformation-controlled unloading, after reaching constant-volume swelling pressure, the specimen is unloaded to 1/16 tsf. However, only a preselected rebound (e.g. 15×10^{-4} inch) is allowed and then swelling is prevented by increasing the axial load until a new swelling pressure is reached at the new void ratio. The process of unloading, allowing a finite swell, and reloading is continued to obtain a relationship between swelling pressure and swelling strain. Data forms 3A, 3B, 3C and 3D are used for the swelling pressure tests.

The step by step procedure is as follows:

1. Cut a 3/4 to 1 inch thick shale disc from the core sample using a motorized band saw. Prepare for trimming of the specimen inside a constant temperature and humidity (T = 15°C and RH = 95%) room.

2. Finish the ends of the shale disc flat and nearly parallel to each other using a surgical blade and a sharp straight edge.

3. Place the shale on the base of a modified Soil Test Compression Tester (Model U-116). This device is used as a press to advance the shale into the confining ring. The base plate and the loading

ram have been equipped with rod bearings to facilitate rotation of the shale specimen during the trimming operation.

4. Center the 1.77 inch (45 mm) stainless steel ring, which is coated inside with a thin film of high vacuum silicone grease, on top of the shale.

5. Bring down the loading ram-bearing assembly to press on the ring, as shown in Fig. 2a.

6. Using a sharp pointed stainless steel surgical blade (Bard Parker No. 10) trim excess shale from around the disc as close as possible to the sharp edge of the confining ring, without undercutting.

7. Continue trimming while rotating the base of the loading press, so that when the ring is advanced about 1 mm, a thin annular layer of shale is removed. The trimming of shale and the advancing of the ring are continued a sufficient number of times until the ring is filled.

8. Remove the ring containing the shale from the press and cut off the excess shale projecting out of the sharp end of the ring. Finish the surface completely flat using surgical blades and a very sharp stainless steel straight edge.

9. Assemble the ring plus shale as shown in Fig. 2b and using a spacer, advance the finished surface 1/8 inch into the ring.

10. Cut off the shale protruding from the opposite end of the ring and finish the surface completely flat using a sharp straight edge.

11. Weigh the ring plus shale and measure the height of the shale specimen.

12. Assemble the ring plus shale inside a consolidation cell, using dry Tetko polyester screen and porous stone at each end.

13. Place the assembled cell in the loading frame.

14. In Wykeham Farrance (WF) lever arm-weight loading frames, lever arm is balanced taking into account weight of the water to be added later into the consolidation cell.

15. Zero the vertical deformation dial gage after leveling under a seating load of 1/16 tsf (6 kPa).

16. Fill the consolidation cell reservoir with distilled water and add load increments as required by the specimen. Load increments should correspond to about 1/4 to 1/8 of the estimated swelling pressure at the specimen void ratio.

17. Add loads with time, allowing for compression of the system in order to maintain volume of the specimen unchanged, until the end-of-primary (EOP) swelling pressure is reached.

18. In WF loading frames, unload the specimen using either load-controlled or deformation-controlled procedure.

19. In load-controlled procedure, unload using load decrement ratios of 3 to 4, allowing at least primary swelling under each decrement.

20. In deformation-controlled procedure, unload to 1/16 tsf (6 kPa) in a single decrement, allow a predetermined rebound (e.g. 15 x 10^{-4} inch), then add weights to prevent any further rebound until a new swelling pressure is measured as in step 17.

21. Repeat step 20 to define a relationship between swelling pressure and axial strain (or void ratio).

22. Alternatively, after step 17 continue loading the specimen in order to measure recompression and compression behavior, using increment ratios of unity and allowing primarily consolidation under each load increment.

23. In the Rigid Frame (RF) load cell system, set up the shale specimen prepared by steps 1 through 12, and zero the axial deformation dials under a seating pressure of about 0.3 tsf.

24. After shale is given access to distilled water, maintain constant volume by adjusting the zero axial deformation dial reading, using a screw control, in order to compensate for a previously calibrated system compression, and measure the swelling pressure development with time by reading the axial load cell.

25. After reaching the EOP swelling pressure, unload the shale specimen, remove it from the ring, weigh it, and place it in an oven to obtain the dry weight.

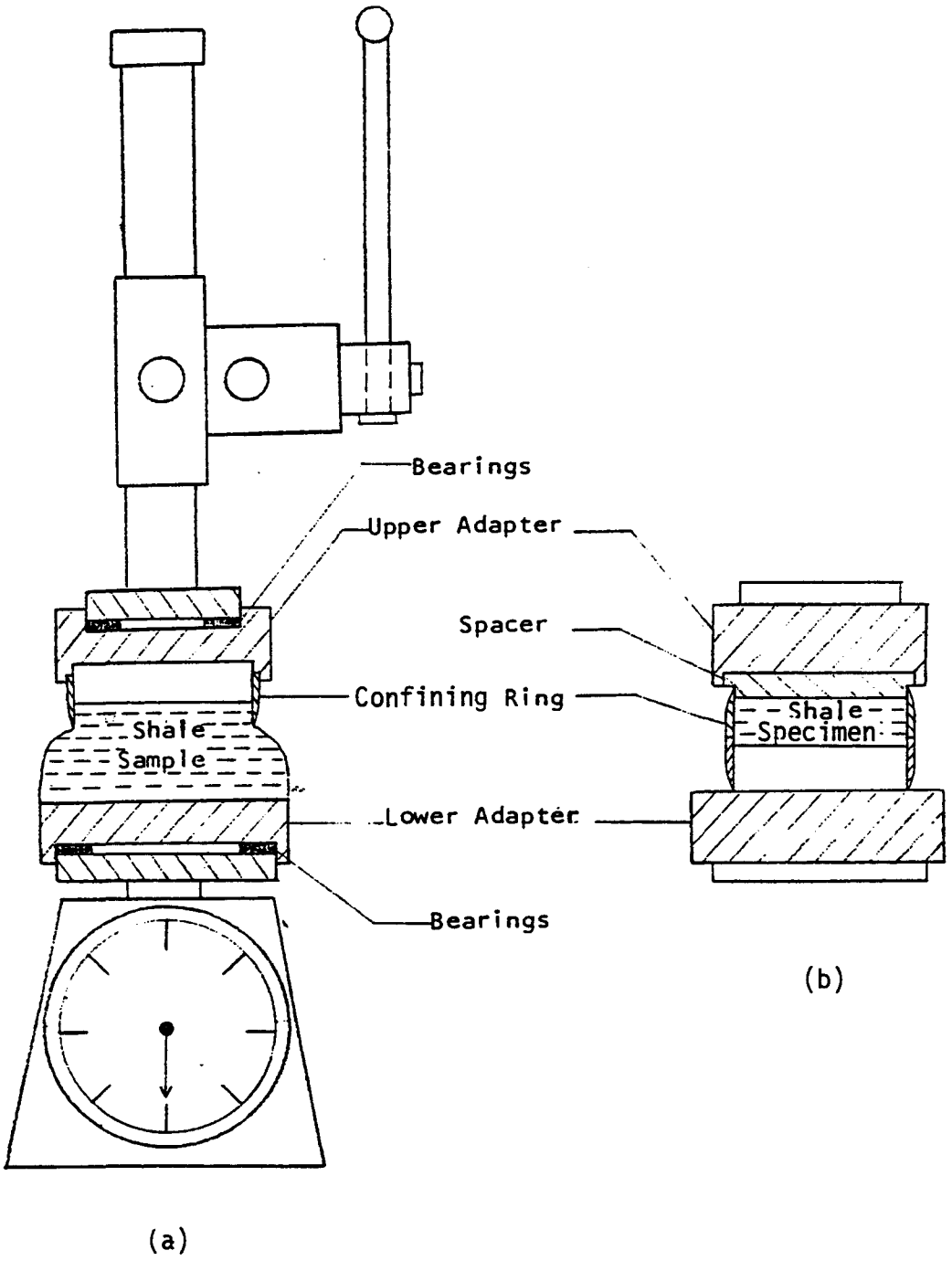


Fig. 2 Trimming of shale specimen for swelling pressure, recompression, compression and swell tests.

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SWELLING PRESSURE, RECOMPRESSION, COMPRESSION, SWELL TEST				
PROJECT		BORING		MATERIAL
TEST NO.		SPECIMEN DIMENSIONS HT., IN _____ DIA. IN _____ AREA. IN^2 _____ VOL. IN^3 _____		SPECIFIC GRAVITY, G_S _____
LOADING SYSTEM		CONFINING RING DIMENSIONS HT., IN _____ I. D., IN _____ MATERIAL _____		TECHNICIAN _____ COMPUTED _____ CHECKED _____
LIQUID LIMIT	PLASTIC LIMIT	TOTAL UNIT WEIGHT	DRY UNIT WEIGHT	DATE

WEIGHT VOLUME AND WATER CONTENT DATA (ALL WEIGHTS IN GRAMS)

	SPECIMEN		AUXILIARY		
	INITIAL	FINAL	1	2	3
WT WET SHALE + CONTAINER					
WT DRY SHALE + CONTAINER					
WT WATER					
WT CONTAINER					
WT DRY SHALE					
WATER CONTENT, %					

INITIAL VOID RATIO AND DEGREE OF SATURATION (ALL VOLUMES IN CM^3)

VOLUME OF SAMPLE	
VOLUME OF SOLIDS	
VOLUME OF VOIDS	
VOID RATIO	
VOLUME OF WATER	
DEGREE OF SATURATION, %	
HEIGHT OF SOLIDS, IN	

FORM 3A

GEOTECHNICAL ENGINEERING LABORATORY, UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

SWELLING PRESSURE, RECOMPRESSION, COMPRESSION, SWELL TEST

PROJECT	BORING	MATERIAL

TEST NO.	TECHNICIAN _____ COMPUTED _____ CHECKED _____

LOAD NUMBER	LOAD NUMBER
TOTAL WEIGHTS	TOTAL WEIGHTS
PRESSURE	PRESSURE
DATE	DATE

CLOCK TIME	ELAPSED TIME mins	DIAL READING	TOTAL DEFORMATION
	0		
	0.10		
	0.25		
	0.5		
	1.0		
	2		
	4		
	8		

CLOCK TIME	ELAPSED TIME mins	DIAL READING	TOTAL DEFORMATION
	0		
	0.10		
	0.25		
	0.5		
	1.0		
	2		
	4		
	8		

FORM 3B

GEOTECHNICAL ENGINEERING LABORATORY, UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

SWELLING PRESSURE TEST IN RIGID FRAME					
PROJECT		BORING		MATERIAL	
TEST NO.		SPECIMEN DIMENSIONS HT. IN _____ DIA. IN _____ AREA, IN^2 _____ VOL. IN^3 _____			SPECIFIC GRAVITY, G_S _____
LOADING SYSTEM		CONFINING RING DIMENSIONS HT., IN _____ I. D., IN _____ MATERIAL _____			TECHNICIAN _____ COMPUTED _____ CHECKED _____
LIQUID LIMIT	PLASTIC LIMIT	TOTAL UNIT WEIGHT	DRY UNIT WEIGHT		DATE

WEIGHT VOLUME AND WATER CONTENT DATA (ALL WEIGHTS IN GRAMS)

	SPECIMEN		AUXILIARY		
	INITIAL	FINAL	1	2	3
WT WET SHALE + CONTAINER					
WT DRY SHALE + CONTAINER					
WT WATER					
WT CONTAINER					
WT DRY SHALE					
WATER CONTENT, %					

INITIAL VOID RATIO AND DEGREE OF SATURATION (ALL VOLUMES IN CM^3)

VOLUME OF SAMPLE	
VOLUME OF SOLIDS	
VOLUME OF VOIDS	
VOID RATIO	
VOLUME OF WATER	
DEGREE OF SATURATION, %	
HEIGHT OF SOLIDS, IN	

FORM 3C

GEOTECHNICAL ENGINEERING LABORATORY, UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

SWELLING PRESSURE TEST IN RIGID FRAME		DATE
PROJECT	BORING	MATERIAL
TEST NO.	SPECIMEN DIMENSIONS HEIGHT, IN _____ AREA, IN^2 _____	TECHNICIAN _____ COMPUTED _____ CHECKED _____
LOAD CELL NO. MODEL _____ SL. NO _____	LOAD CELL CONSTANT LB/DIV _____	

CLOCK TIME	ELAPSED TIME MINS	INITIAL LOAD CELL READING	INITIAL LOAD CELL CHANGE	REQUIRED DIAL READING	FINAL LOAD CELL READING	FINAL LOAD CELL CHANGE	LEFT DIAL READING	RIGHT DIAL READING	AVERAGE DIAL READING	INITIAL LOAD LBS	FINAL LOAD LBS	INITIAL PRESSURE TSF	FINAL PRESSURE TSF

FORM 3D

SUPERCONDUCTING SUPER COLLIDER PROJECT, WAXAHACHIE, TEXAS

SWELLING PRESSURE, RECOMPRESSION, COMPRESSION, SWELL TEST

PROJECT SSC	BORING		MATERIAL
TEST NO.	SPECIMEN DIMENSIONS HT., IN _____ DIA. IN _____ AREA, IN^2 _____ VOL. IN^3 _____		SPECIFIC GRAVITY, G_s _____
LOADING SYSTEM	CONFINING RING DIMENSIONS HT., IN _____ I. D., IN _____ MATERIAL _____		TECHNICIAN _____ COMPUTED _____ CHECKED _____
LIQUID LIMIT / PLASTIC LIMIT	TOTAL UNIT WEIGHT	DRY UNIT WEIGHT	DATE

WEIGHT VOLUME AND WATER CONTENT DATA (ALL WEIGHTS IN GRAMS)

	SPECIMEN		AUXILIARY		
	INITIAL	FINAL	1	2	3
WT WET SHALE + CONTAINER					
WT DRY SHALE + CONTAINER					
WT WATER					
WT CONTAINER					
WT DRY SHALE					
WATER CONTENT, %					

INITIAL VOID RATIO AND DEGREE OF SATURATION (ALL VOLUMES IN CM^3)

VOLUME OF SAMPLE	
VOLUME OF SOLIDS	
VOLUME OF VOIDS	
VOID RATIO	
VOLUME OF WATER	
DEGREE OF SATURATION, %	
HEIGHT OF SOLIDS, IN	

FORM 3A

SUPERCONDUCTING SUPER COLLIDER PROJECT, WAXAHACHIE, TEXAS

SWELLING PRESSURE, RECOMPRESSION, COMPRESSION, SWELL TEST

PROJECT SSC	BORING	MATERIAL

TEST NO.	TECHNICIAN _____ COMPUTED _____ CHECKED _____

LOAD NUMBER	LOAD NUMBER
TOTAL WEIGHTS	TOTAL WEIGHTS
PRESSURE	PRESSURE
DATE	DATE

CLOCK TIME	ELAPSED TIME mins	DIAL READING	TOTAL DEFORMATION
	0		
	0.10		
	0.25		
	0.5		
	1.0		
	2		
	4		
	8		

CLOCK TIME	ELAPSED TIME mins	DIAL READING	TOTAL DEFORMATION
	0		
	0.10		
	0.25		
	0.5		
	1.0		
	2		
	4		
	8		

FORM 3B

SUPERCONDUCTING SUPER COLLIDER PROJECT, WAXAHACHIE, TEXAS

SWELLING PRESSURE TEST IN RIGID FRAME

PROJECT SSC		BORING		MATERIAL
TEST NO.		SPECIMEN DIMENSIONS HT. IN _____ DIA. IN _____ AREA, IN^2 _____ VOL. IN^3 _____		SPECIFIC GRAVITY, G_S _____
LOADING SYSTEM		CONFINING RING DIMENSIONS HT., IN _____ I. D., IN _____ MATERIAL _____		TECHNICIAN _____ COMPUTED _____ CHECKED _____
LIQUID LIMIT	PLASTIC LIMIT	TOTAL UNIT WEIGHT	DRY UNIT WEIGHT	DATE

WEIGHT VOLUME AND WATER CONTENT DATA (ALL WEIGHTS IN GRAMS)

	SPECIMEN		AUXILIARY		
	INITIAL	FINAL	1	2	3
WT WET SHALE + CONTAINER					
WT DRY SHALE + CONTAINER					
WT WATER					
WT CONTAINER					
WT DRY SHALE					
WATER CONTENT, %					

INITIAL VOID RATIO AND DEGREE OF SATURATION (ALL VOLUMES IN CM^3)

VOLUME OF SAMPLE	
VOLUME OF SOLIDS	
VOLUME OF VOIDS	
VOID RATIO	
VOLUME OF WATER	
DEGREE OF SATURATION, %	
HEIGHT OF SOLIDS, IN	

FORM 3C

SUPERCONDUCTING SUPER COLLIDER PROJECT, WAXAHACHIE, TEXAS

SWELLING PRESSURE TEST IN RIGID FRAME		DATE
PROJECT SSC	BORING	MATERIAL
TEST NO.	SPECIMEN DIMENSIONS HEIGHT, IN _____ AREA, IN^2 _____	TECHNICIAN _____ COMPUTED _____ CHECKED _____
LOAD CELL NO. MODEL _____ SL. NO _____	LOAD CELL CONSTANT LB/DIV _____	

CLOCK TIME	ELAPSED TIME MINS	INITIAL LOAD CELL READING	INITIAL LOAD CELL CHANGE	REQUIRED DIAL READING	FINAL LOAD CELL READING	FINAL LOAD CELL CHANGE	LEFT DIAL READING	RIGHT DIAL READING	AVERAGE DIAL READING	INITIAL LOAD LBS	FINAL LOAD LBS	INITIAL PRESSURE TSF	FINAL PRESSURE TSF

FORM 3D

4. Recompression and Compression Tests

After reaching the constant volume swelling pressure, some specimens of Eagle Ford shale and Taylor marl are loaded to measure the recompression characteristics. Primary compression is allowed under all pressure increments. After reaching a maximum pressure of 64 tsf, the specimen is unloaded in decrements allowing only primary swelling.

Recompression and compression of shale are measured either after the swelling pressure measurements as in step 22 in Section 3, or when higher maximum pressures are desired, compression tests are carried out in a Multi Purpose (MP) lever arm-weight loading system. In this system the confining ring is mounted inside a triaxial cell as shown in Fig. 3a. In the MP loading system the lever arm ratio is 15:1 and a maximum axial pressure of 280 tsf (27 MPa) can be applied to a 1.77 inch (45 mm) diameter specimen (see Fig. 3b). Data sheets 3A and 3B are used for recompression and compression tests.

1. Prepare the shale specimen as per steps 1 through 11 in section 3.

2. Set up the shale plus confining ring on the base of the triaxial cell, as in Fig. 3a.

3. Assemble the triaxial cell and seat the piston, which enters the cell through a bushing system, on the loading cap using a seating pressure of about 1 tsf (100 kPa).

4. Fill the cell with distilled water and as soon as specimen obtains access to water increase axial load to maintain a constant volume condition.

5. Increase axial load, taking into account system compression until the EOP swelling pressure is reached.

6. Load the shale specimen beyond the swelling pressure using a load increment ratio of unity, allowing primary consolidation under all pressure increments. This loading and the corresponding compression data are used to determine recompression and compression characteristics of the shale.

7. Unload the shale specimen using a decrement ratio of 3 to 4, allowing at least EOP swelling under each pressure decrement.

8. After the completion of the test, remove specimen from the ring, obtain a total weight, and then oven dry to obtain dry weight of the specimen.

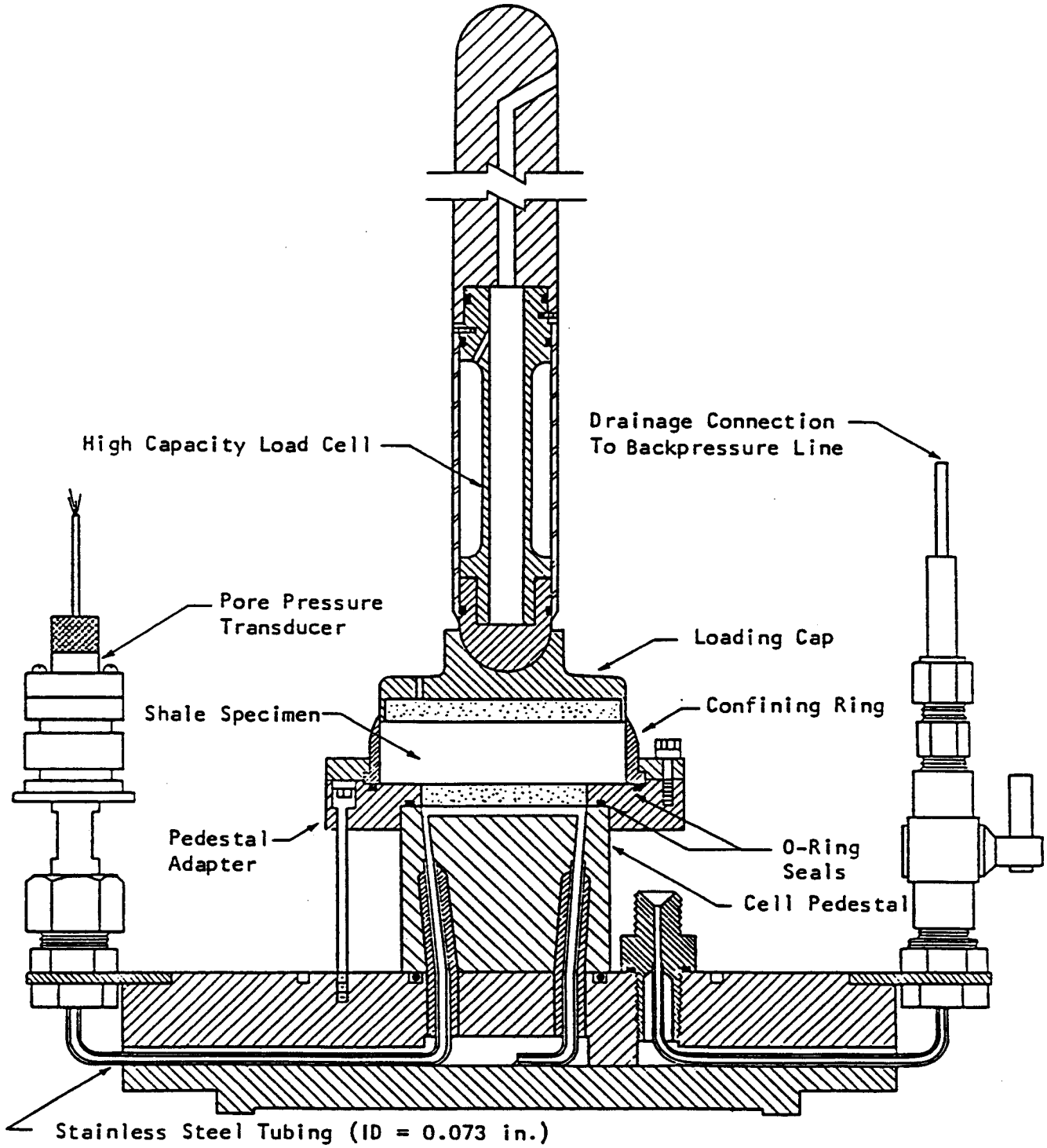

Fig. 3a Confining ring for swelling pressure, recompression, compression, and swell, mounted inside a triaxial cell.

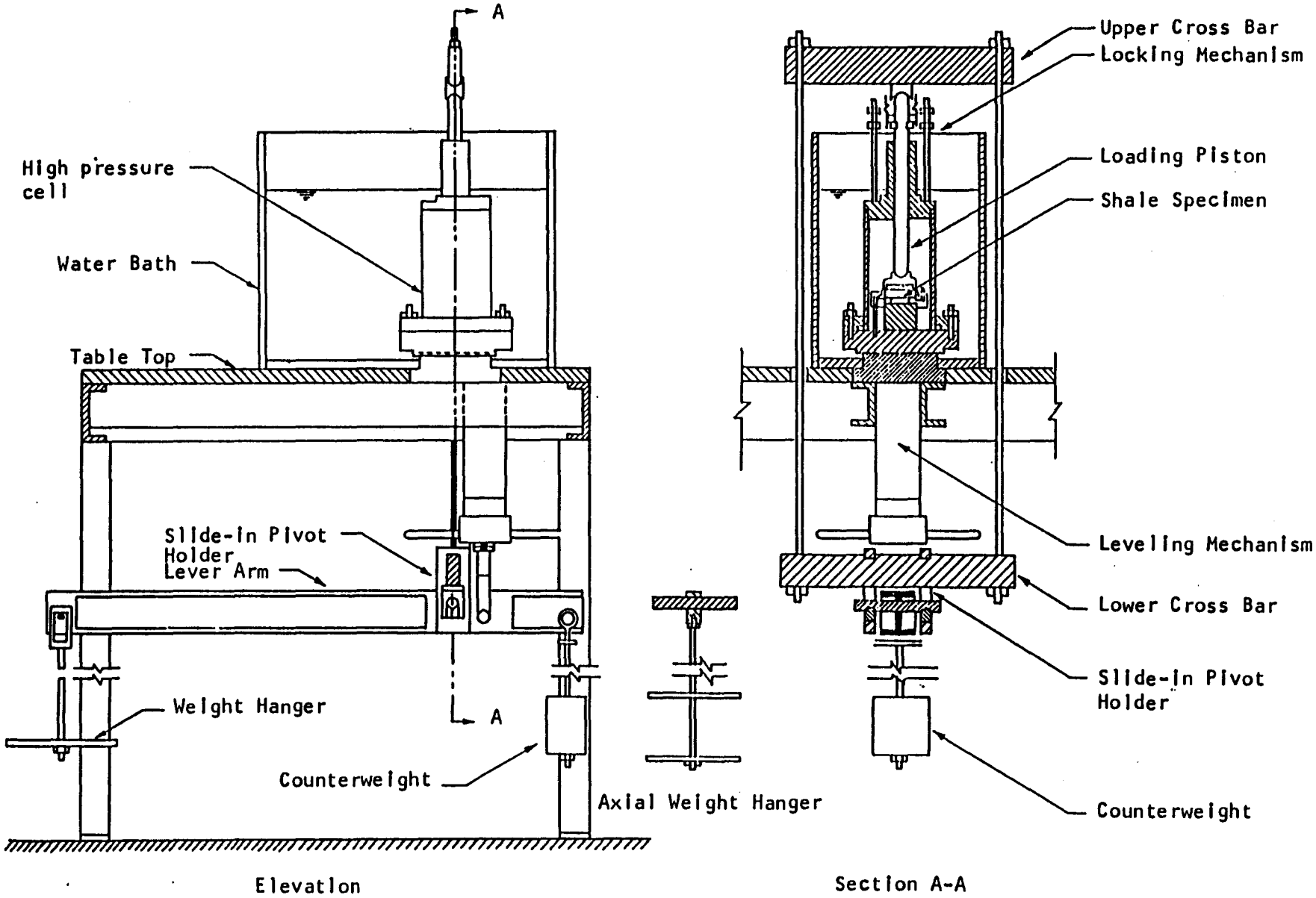

Fig. 3b Loading arrangement for MP system.

5. Deterioration Tests

Intact shale specimens with average dimensions of 2 to 3 inches are subjected to increments or decrements of relative humidity RH, and the changes in moisture content are measured, and opening of bedding planes, laminations or formation of joints and fissures are observed and recorded with time. Two Hotpack environmental test chambers are being used. One unit, Hotpack 412465, can accommodate 30 specimens. The second unit, Hotpack 417530 has a capacity for 60 specimens. Duplicate specimens of each shale sample are placed on a stainless steel wire mesh basket suspended over a porcelain dish, and are exposed to environments with different moisture contents, determined by relative humidity RH, and temperature T. The temperature is maintained at a value in the range of 50 to 60°F, and RH is cycled in increments or decrements in the range of 45 to 99%. The response of exposed shale to wet and dry environments is summarized in plots of water content change against time, and final primary water content change against RH. Data form 5A is used for the deterioration test.

The step by step procedure is as follows:

1. Select duplicate intact specimens of shale with an average dimension of 2 to 3 inches. The specimen for the deterioration test should preferably have boundaries determined by such natural discontinuities as laminations, bedding plans, fissures, shear or fracture surfaces. Therefore, the specimen is to be 'broken' into the required size, rather than cut or trimmed. Using a stiff brush, remove the loose surface material, remolded or softened during sampling operation.

2. Take separate set of water content samples to determine initial water content of deterioration test specimen.

3. Place the deterioration test specimen on a Tetko stainless steel wire mesh basket suspended over a porcelain dish.

4. Note and sketch the shape and condition of the specimen in terms of initial natural macro fabric such as laminations, fissures and joints if any.

5. Weigh the specimen plus porcelain dish wire mesh system and immediately place it into the environmental chamber. The deterioration test generally starts from a wet chamber environment, such as RH = 99% and T = 55°F (13°C).

6. Remove the specimen from the environmental chamber at geometric time intervals and weigh it, and note and record the condition of the specimen.

7. Continue step 6 until at least EOP drying or wetting condition is reached.

8. Decrease moisture content of air in the chamber, such as to RH = 70%, T = 55°F, and repeat steps 6 and 7.

9. Repeat step 8 until RH = 45% is reached.

10. Increase moisture content of air in the chamber (such as RH = 70%, T = 55°F) and repeat steps 6 and 7.

11. Continue step 10 until RH = 99% is reached.

12. If after step 11, i.e. one dry-wet cycle, shale specimen is completely deteriorated into pieces, stop the test, and oven dry the specimen.

13. Prepare a plot of EOP water content against RH (or against computed suction pressure) for the dry-wet cycle.

14. If the specimen has suffered no or minor deterioration, subject it to a second dry-wet cycle as per steps 5 through 13.

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ENVIRONMENTAL CONTROLLED DETERIORATION TEST

PROJECT	BORING	MATERIAL

TEST NO.	SPECIMEN DIMENSIONS HT., IN _____ DIA., IN_____ VOL., IN³ _____	INITIAL WATER CONTENT
DATE	SPECIMEN WEIGHT TARE NO. _____ WT SPECIMEN + TARE _____ WT TARE _____ WT SPECIMEN _____	SPECIMEN SHAPE
TECHNICIAN _____ COMPUTED _____ CHECKED _____	CONTROL CHAMBER	

	1	2
CONTAINER NO.		
WT SHALE + CONTAINER		
WT DRY SHALE + CONTAINER		
WT WATER		
WT CONTAINER		
WT DRY SHALE		
WATER CONTENT, %		

DATE	TIME	ELAPSED TIME mins	RH %	TEMP °C	WEIGHT gms	WEIGHT CHANGE gms	WATER CONTENT %	WATER CONTENT CHANGE %	SPECIMEN DESCRIPTION

FORM 5A

SUPERCONDUCTING SUPER COLLIDER PROJECT, WAXAHACHIE, TEXAS

ENVIRONMENTAL CONTROLLED DETERIORATION TEST

PROJECT SSC	BORING	MATERIAL

TEST NO.	SPECIMEN DIMENSIONS HT., IN _____ DIA., IN _____ VOL., IN³ _____	INITIAL WATER CONTENT

DATE	SPECIMEN WEIGHT TARE NO. _____ WT SPECIMEN + TARE _____ WT TARE _____ WT SPECIMEN _____	SPECIMEN SHAPE
TECHNICIAN _____ COMPUTED _____ CHECKED _____	CONTROL CHAMBER	

	1	2
CONTAINER NO.		
WT SHALE + CONTAINER		
WT DRY SHALE + CONTAINER		
WT WATER		
WT CONTAINER		
WT DRY SHALE		
WATER CONTENT, %		

DATE	TIME	ELAPSED TIME mins	RH %	TEMP °C	WEIGHT gms	WEIGHT CHANGE gms	WATER CONTENT %	WATER CONTENT CHANGE %	SPECIMEN DESCRIPTION

FORM 5A

6. Atterberg Limit Tests

The Atterberg liquid limit is in effect a measure of the ability of the soil composition to hold water. Water associates with soil particles either through hydration of particle surfaces (adsorbed water) or hydration of ions surrounding the surfaces (double-layer water). As the particle size decreases and therefore the particle surface area per unit weight increases, the liquid limit is expected to increase. Sample preparation for the liquid limit test should allow the individual clay mineral particles to be completely hydrated. Since some shales are highly aggregated, sample preparation for the measurements of Atterberg limits must include a reproducible disaggregation process. For this purpose, samples of Eagle Ford shale and Taylor marl are being air dried and then ball milled until all of a representative sample passes No. 200 sieve. After ball milling, the shale is thoroughly rehydrated using tempering time of at least 1 week. Liquid limit is being determined using the Casagrande device and by the multi-point method (at least 4 water contents). Data form 6A is used for Atterberg limit tests.

These tests are carried out basically according to the ASTM D4318-84. Special procedure for disaggregation of the clay particles is considered necessary for the shales being tested for this project. The following description of the test procedure covers the significant steps in the preparation of the samples for Atterberg limit tests.

1. Take about 150 gms of air dried material.

2. Pulverize the material using mortar and pestle.

3. Place about 10 to 15 gms of pulverized sample into the ball milling cup. Add the stainless steel balls and place the cup in the ball milling machine. Set the timer to ball mill for about 10 minutes. Avoid any heating up of the sample due to continuous running of the ball milling over a prolonged period of time.

4. Place the powdered material from the ball milling cup on a No. 200 sieve and shake the sieve. Put the portion of the material retained on No. 200 sieve back into the ball milling cup and repeat the process until all of the material passes through No. 200 sieve.

5. Add distilled water to the ball milled sample and thoroughly rehydrate it allowing a tempering time of at least 1 week.

6. Determine the liquid limit according to ASTM D4318-84 using Casagrande device and by the multi-point method (at least 4 water contents).

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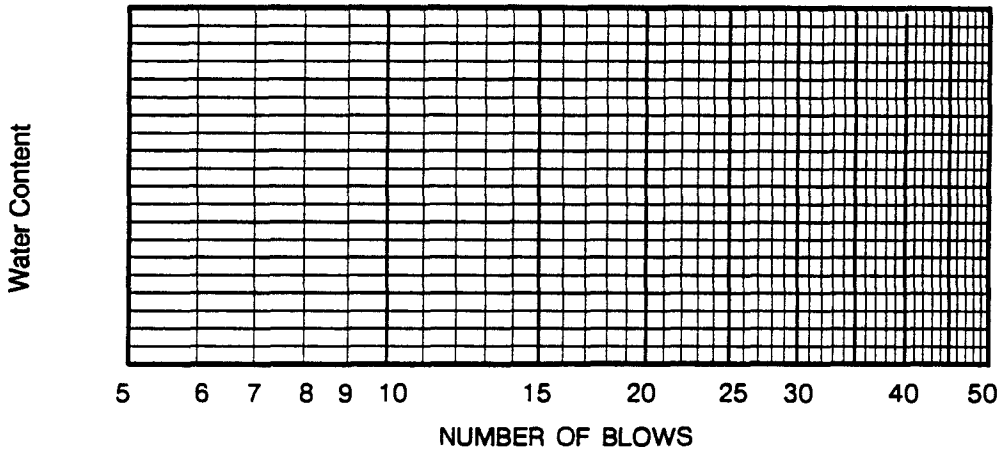
ATTERBERG LIMIT DETERMINATION	DATE
PROJECT	MATERIAL
BORING	SAMPLE IDENTIFICATION

LIQUID LIMIT

RUN NUMBER	1	2	3	4	5	6
CONTAINER NO.						
WT WET SOIL + CONTAINER						
WT DRY SOIL + CONTAINER						
WT WATER						
WT CONTAINER						
WT DRY SOIL						
WATER CONTENT, %						
NO. OF BLOWS						



L L	
P L	
P I	

PLASTIC LIMIT

RUN NUMBER	1	2	3	4	5	NATURAL WATER CONTENT
CONTAINER NO.						
WT WET SOIL + CONTAINER						
WT DRY SOIL + CONTAINER						
WT WATER						
WT CONTAINER						
WT DRY SOIL						
WATER CONTENT, %						

REMARKS

TECHNICIAN	COMPUTED	CHECKED

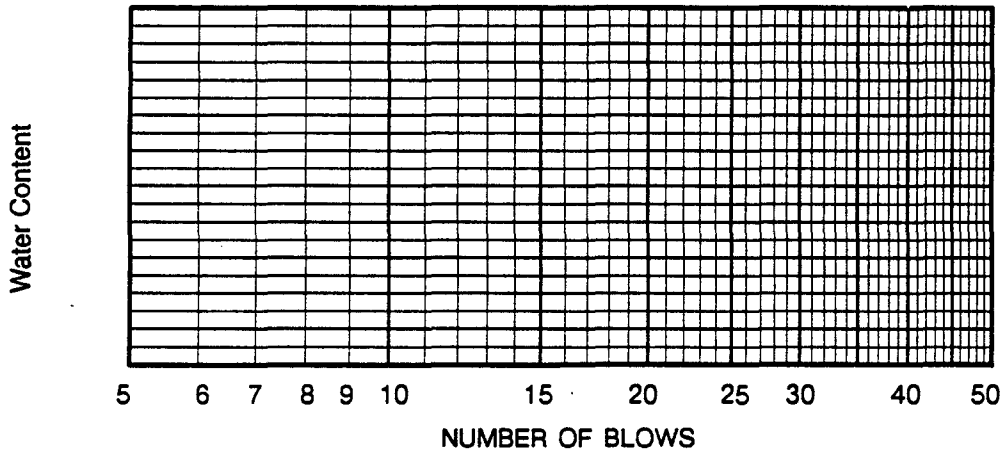
FORM 6A

SUPERCONDUCTING SUPER COLLIDER PROJECT, WAXAHACHIE, TEXAS

ATTERBERG LIMIT DETERMINATION	DATE
PROJECT	MATERIAL
BORING	SAMPLE IDENTIFICATION

LIQUID LIMIT

RUN NUMBER	1	2	3	4	5	6
CONTAINER NO.						
WT WET SOIL + CONTAINER						
WT DRY SOIL + CONTAINER						
WT WATER						
WT CONTAINER						
WT DRY SOIL						
WATER CONTENT, %						
NO. OF BLOWS						



L L	
P L	
P I	

PLASTIC LIMIT

RUN NUMBER	1	2	3	4	5	NATURAL WATER CONTENT
CONTAINER NO.						
WT WET SOIL + CONTAINER						
WT DRY SOIL + CONTAINER						
WT WATER						
WT CONTAINER						
WT DRY SOIL						
WATER CONTENT, %						

REMARKS

TECHNICIAN	COMPUTED	CHECKED

FORM 6A

7. Water Content

Water content is determined basically according to ASTM D2216-80. The natural water content of the shale samples being tested for this project is low and generally ranges between 15 to 20%. The following steps describe the procedure considered to be essential for obtaining accurate water content measurements.

1. Weigh the containers once after they are oven-dried and also after they have been exposed to the temperature and humidity controlled room. Use the oven-dried weight of container to calculate the weight of oven-dried specimen and use the weight of container in humidity controlled room when calculating the weight of the moist specimen.

2. For the determination of natural water content, use 40 to 50 gms of shale consisting of about 20 gm chunks. Avoid thin (flaky) trimmings which lose moisture very rapidly.

3. For water content determination during Atterberg limit tests, use about 10 to 15 gms of shale.

4. Oven-dry the samples in a thermostatically-controlled oven, maintaining a uniform temperature of 110 ± 5°C throughout the chamber without the use of forced-draft. Oven-dry the samples for a period of about 24 hours.

8. Carbonate Content

Carbonates can act as cementing agent between silicate mineral particles in shales and thus can have significant effect on the engineering properties and behavior of the shales. Carbonate content is being determined by using a 1 N NaOAc buffer as recommended by Jackson, M. L. (Soil Chemical Analysis - Advanced Course). The 1 N NaOAc buffer of pH 5.0 is prepared by mixing 82 gm of Sodium Acetate (NaOAc) and 27 ml of glacial Acetic Acid (HOAC) with distilled water to obtain 1000 ml of buffer solution. The buffer treatment with NaOAc dissolves finely divided carbonate particles, including dolomite. Compared to treatment with HCL, the 1 N NaOAc buffer is much gentler to the clay mineral particles. In order to determine the carbonate content that may act as cementing agent, the calcareous shell fragments are first removed by sieving the slaked shale on No. 200 sieve. The buffer treatment is done only on the fraction passing No. 200 sieve which is assumed to be free of calcareous shell fragments. Data form 7A is used for carbonate content determination.

Procedure:

1. Select a sample of shale weighing about 50 gms and oven-dry it in an oven at 110 ± 5°C. Record the oven-dried weight of the sample.

2. Immerse the oven-dried chunk into distilled water and allow it to slake for about 24 hours.

3. Pour the slaked shale on a No. 200 sieve and wash it with distilled water. Use gentle finger pressure to break up shale

aggregates. Collect all the material passing through No. 200 sieve.

4. Oven-dry both the portion retained as well as passing the No. 200 sieve.

5. Weigh the oven-dried materials obtained in step 4. Calculate the percentage of material passing No. 200 sieve.

6. Place 5 gms of material passing No. 200 sieve in a 100-ml centrifuge tube. Use duplicate samples.

7. Add 50 ml of pH 5.0 NaOAc buffer to each centrifuge tube containing 5 gms of shale material.

8. Stir the centrifuge tube and bring the shale material into suspension.

9. Digest the suspension in a near-boiling water bath for 30 minutes with intermittent stirring.

10. Centrifuge the suspension until the supernatant liquid is clear. Carefully decant the clear supernatant liquid making sure no shale particles are lost.

11. To complete the decomposition of the carbonates, repeat steps 7 to 10.

12. Carefully wash out the shale particles from the centrifuge tube into a pre-weighed beaker.

13. Place the beaker in an oven and allow the shale to dry completely.

14. Weigh the oven-dried material. From the difference between this weight and the weight of material initially put in the centrifuge tube, calculate the carbonate content.

GEOTECHNICAL ENGINEERING LABORATORY, UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

CARBONATE CONTENT DETERMINATION

PROJECT	BORING	MATERIAL
TEST NO.	TECHNICIAN _____ COMPUTED _____ CHECKED _____	DATE

BUFFER
TYPE _____ QUANTITY _____ NO. OF WASHING _____

CENTRIFUGE
MODEL _____ RPM _____ TIME _____

SHALE SPECIMEN (ALL WEIGHTS IN GRAMS)

CONTAINER NO.	
WT DRY SHALE + CONTAINER	
WT CONTAINER	
WT DRY SHALE SPECIMEN	

AFTER WASHING ON NO. 200 SIEVE

	MATERIAL RETAINED ON NO. 200 SIEVE	MATERIAL PASSING NO. 200 SIEVE
CONTAINER NO.		
WT DRY SHALE + CONTAINER		
WT CONTAINER		
WT DRY SHALE		
PASSING NO. 200 SIEVE, %		

BUFFER TREATMENT

	BEFORE TREATMENT		AFTER TREATMENT	
	SAMPLE 1	SAMPLE 2	SAMPLE 1	SAMPLE 2
CONTAINER NO.				
WT DRY SHALE + CONTAINER				
WT CONTAINER				
WT DRY SHALE				
CARBONATE CONTENT, %				

FORM 7A

SUPERCONDUCTING SUPER COLLIDER PROJECT, WAXAHACHIE, TEXAS

CARBONATE CONTENT DETERMINATION

PROJECT SSC	BORING	MATERIAL
TEST NO.	TECHNICIAN _____ COMPUTED _____ CHECKED _____	DATE

BUFFER

TYPE _____ QUANTITY _____ NO. OF WASHING _____

CENTRIFUGE

MODEL _____ RPM _____ TIME _____

SHALE SPECIMEN (ALL WEIGHTS IN GRAMS)

CONTAINER NO.	
WT DRY SHALE + CONTAINER	
WT CONTAINER	
WT DRY SHALE SPECIMEN	

AFTER WASHING ON NO. 200 SIEVE

	MATERIAL RETAINED ON NO. 200 SIEVE	MATERIAL PASSING NO. 200 SIEVE
CONTAINER NO.		
WT DRY SHALE + CONTAINER		
WT CONTAINER		
WT DRY SHALE		
PASSING N0. 200 SIEVE, %		

BUFFER TREATMENT

	BEFORE TREATMENT		AFTER TREATMENT	
	SAMPLE 1	SAMPLE 2	SAMPLE 1	SAMPLE 2
CONTAINER NO.				
WT DRY SHALE + CONTAINER				
WT CONTAINER				
WT DRY SHALE				
CARBONATE CONTENT, %				

FORM 7A

APPENDIX BI

Quality Assurance Documentation of Laboratory Test Procedures PIF Program

Quality Assurance Documentation of
Laboratory Test Procedures - PIF Program

Sample Tracking/Custody

As soon as the samples were delivered by Federal Express, the package was taken inside the humidity and temperature controlled room. The wax-sealed core samples were then carefully taken out of the packaging and the seals were checked and resealed if necessary. The information on the identification tag attached to the core was compared to the information given in the Laboratory Test Assignment sheet for that core sent by SSC Geotechnical Laboratory along with the cores. Once all the information was found to tally, the core samples were considered to have been received in order, and SSC Geotechnical Laboratory was informed accordingly. The receiving, checking and tracking of the samples are being carried out by graduate research assistant M. Shawkat Ali who is working toward his Ph.D. degree and is participating in the testing program for the geological material from SSC project.

During the testing of the core samples, test numbers are given sequentially such as PIFUU1 and PIFUU2 and the bore hole number and depth of the core are also carefully recorded as a part of the test number and test identification.

Sample Storage

The wax-sealed core samples are being stored on stainless steel shelves inside a 18 ft x 10 ft temperature and humidity controlled room. The temperature inside the room is maintained at 15°C and the relative humidity (RH) is maintained at 95 ± 2%. A highly sensitive temperature and humidity control system manufactured by Forma Scientific, Marietta, OH is being used to maintain

the constant temperature and relative humidity inside the room. Specimen preparation for testing is also carried out inside the temperature-humidity controlled room.

Calibration of Equipment

All the equipment used for the testing program are of the highest quality and are well maintained and calibrated at frequent intervals. The proving rings and the load cell used for the measurement of loads in the Drained Reversal Direct Shear tests, Unconsolidated Undrained Triaxial Compression tests and Rigid Frame Swell Pressure tests were calibrated on April 5, 1990 and the calibration results are shown in Figs. 1 to 7. The calibration of the proving rings was done by applying loads by a 10,000 lb capacity Riehle testing machine, serial No. R-92628. The smallest division in the load gage of the Riehle testing machine corresponds to 10 lbs. The testing machine was calibrated by Calser Corporation, Belleville, IL on March 20, 1990 and the next calibration is due on March 20, 1991. The ring used by Calser Corporation to calibrate our Riehle test machine is traceable to the National Institute for Standards and Technology, Washington, D.C. The calibration of the load cell in the Rigid Frame swell pressure apparatus was carried out using Wykeham Farrance Consolidation Loading Frames.

Machine deflection (i.e. deformation due to the compression of the loading system, filter papers and porous stones) is taken into account in determining the net deformation of the specimen in the swelling pressure, recompression, compression, and rebound tests using the Wykeham Farrance frames, the Rigid Frame and the Multipurpose Testing system. Figures 8 to 12 show the machine deflection curves for the different testing frames.

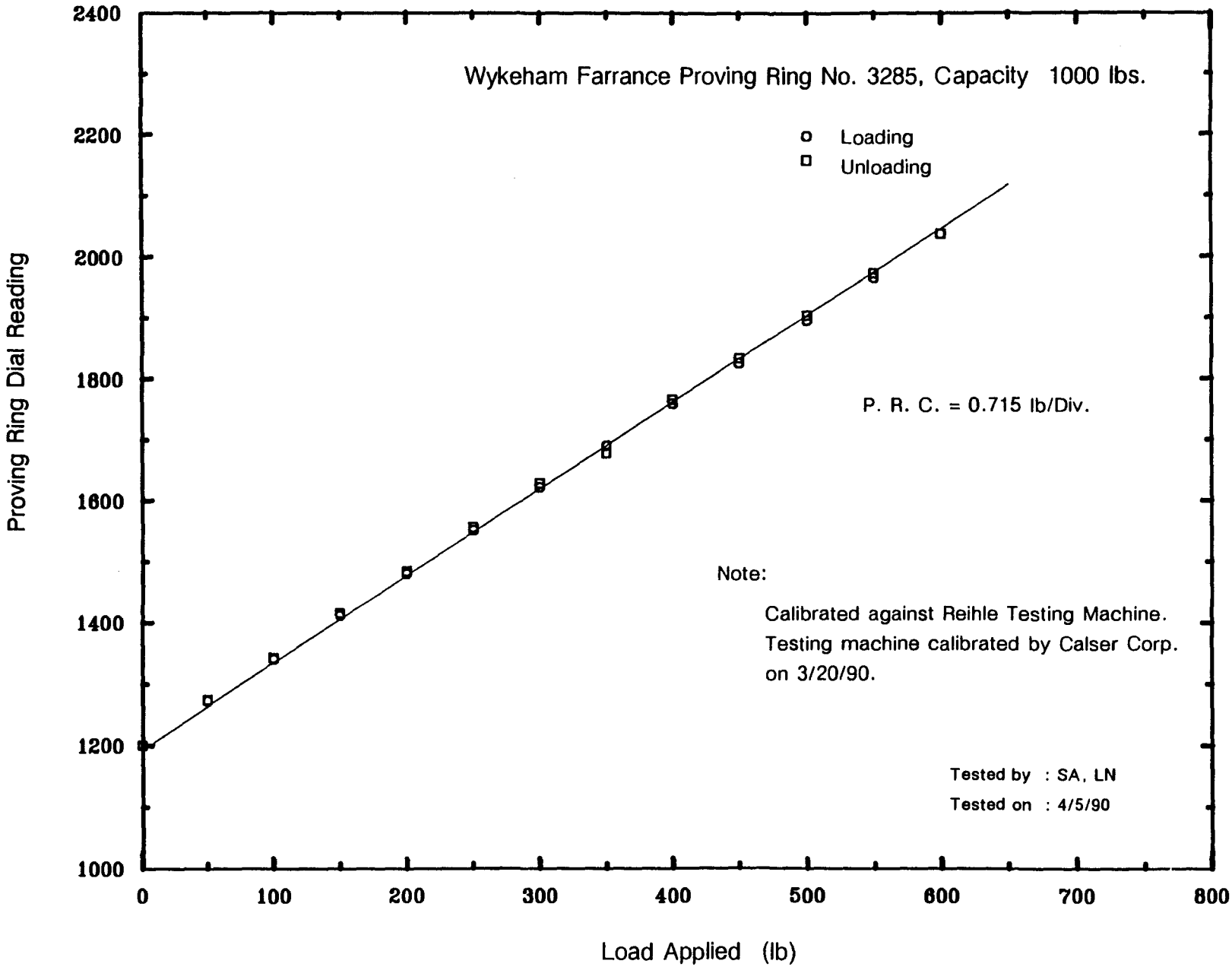


Fig. 1 Calibration of Proving for Compression

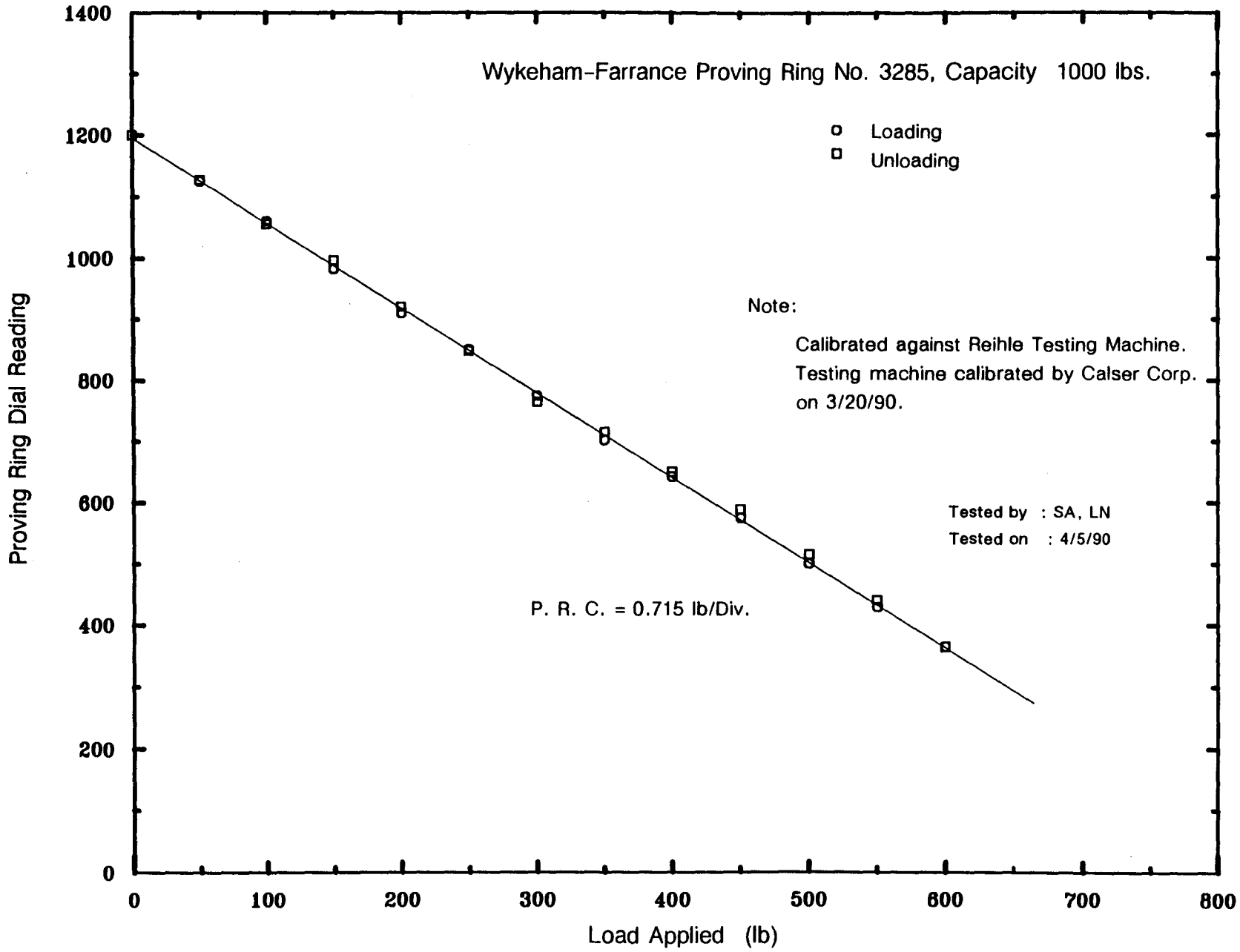


Fig. 2 Calibration of Proving Ring for Tension

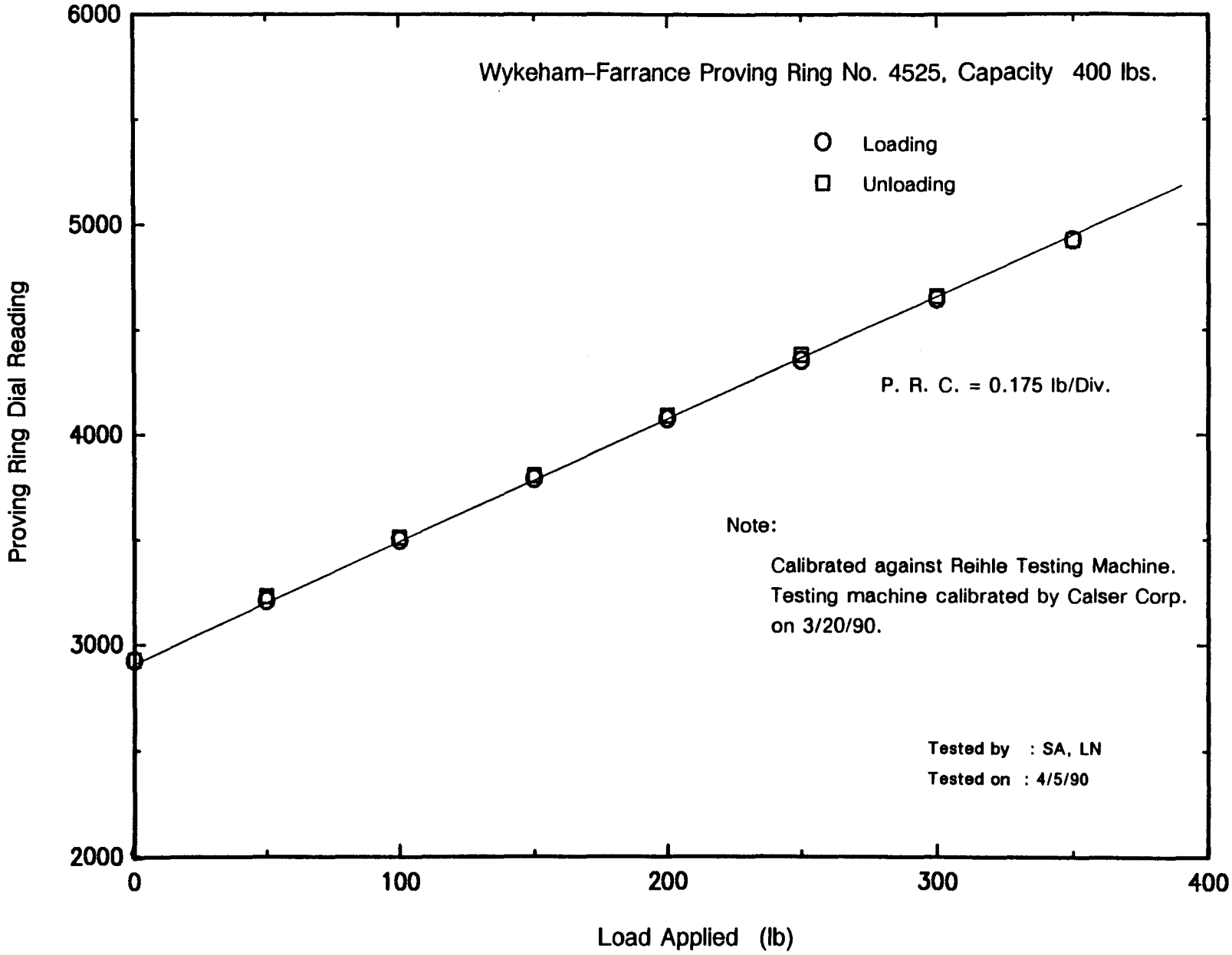


Fig. 3 Calibration of Proving Ring for Compression

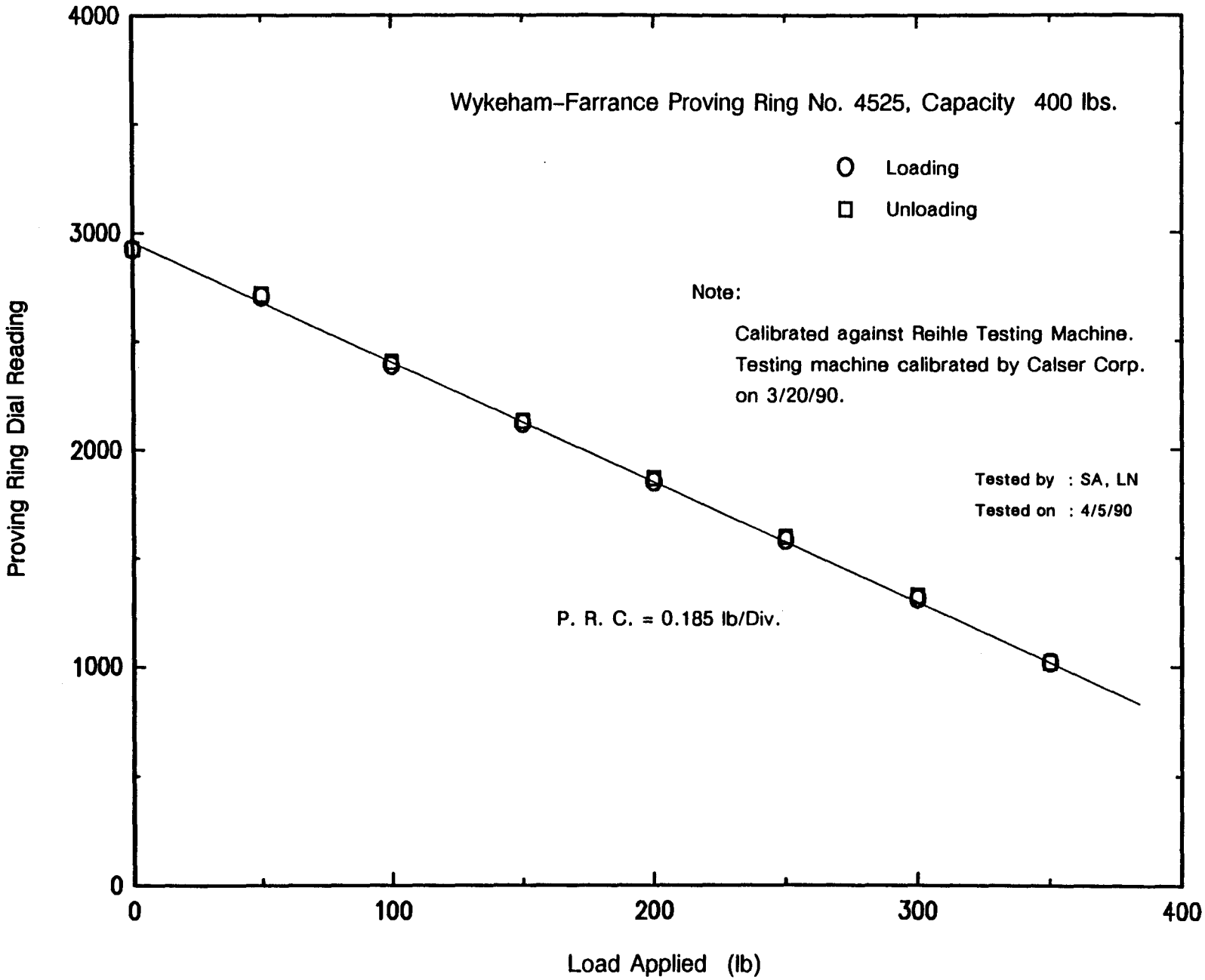


Fig. 4 Calibration of Proving Ring for Tension

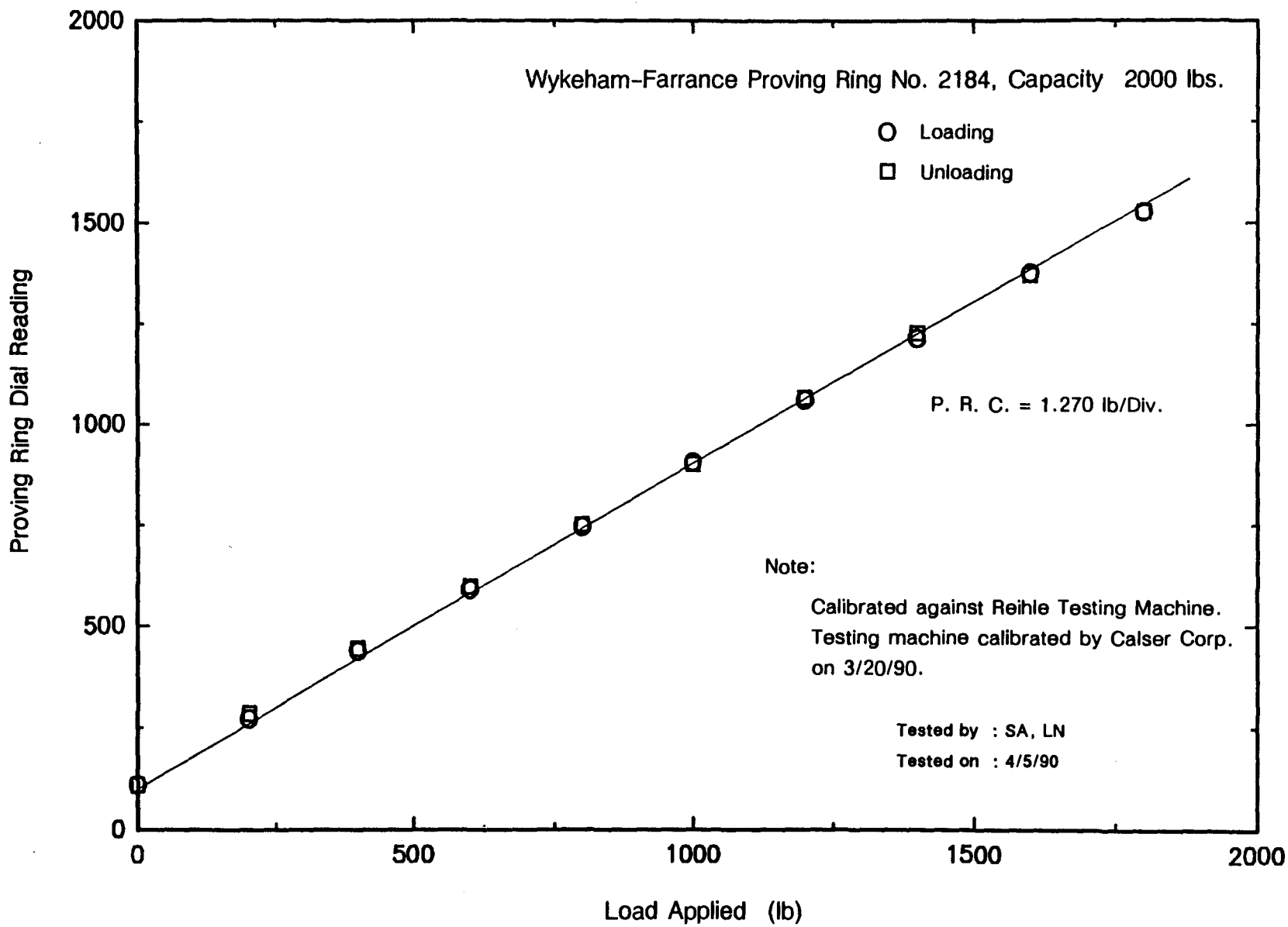


Fig. 5 Calibration of Proving Ring for Compression

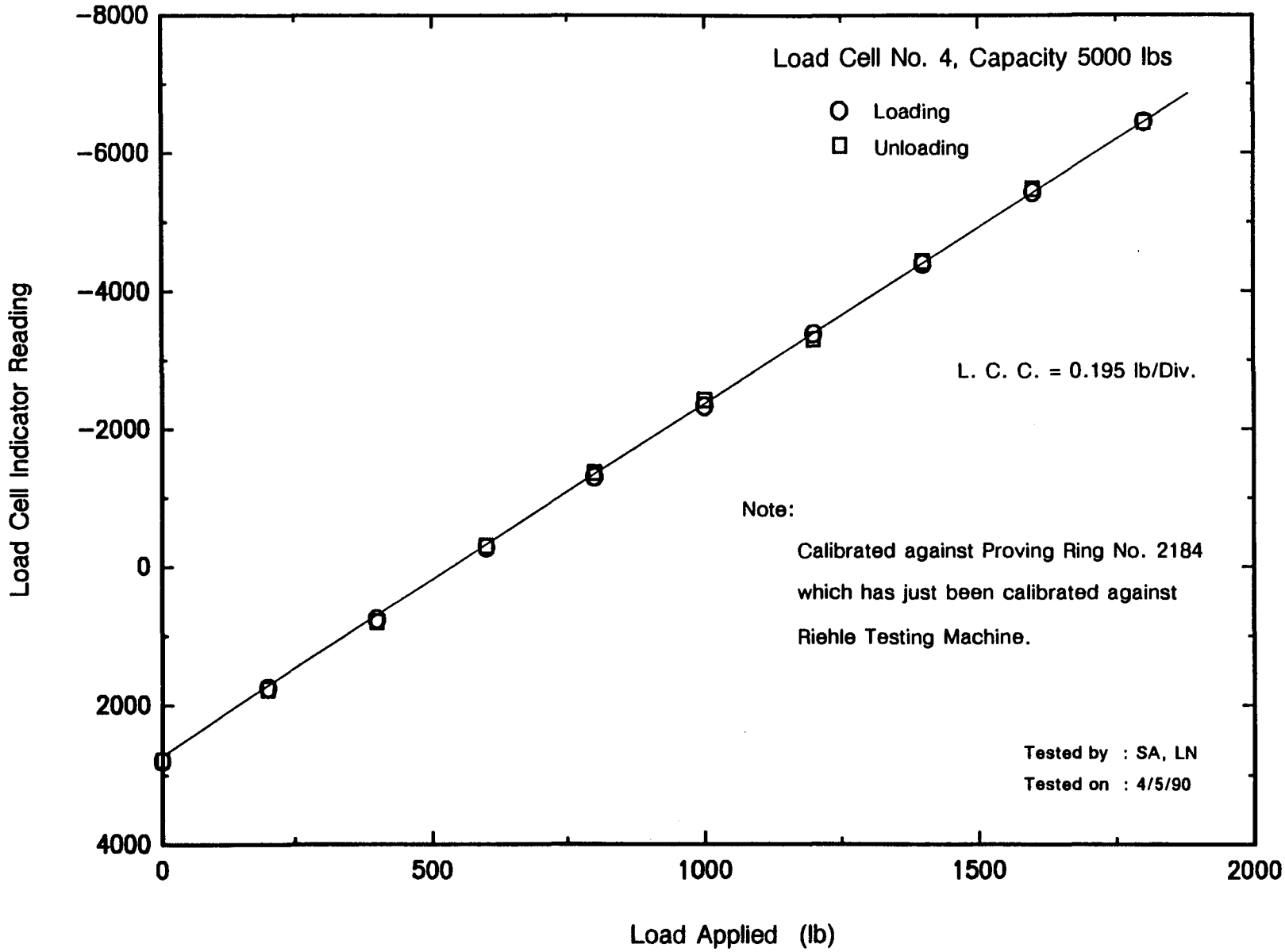


Fig. 6 Calibration of Load Cell Attached to Triaxial Cell Piston

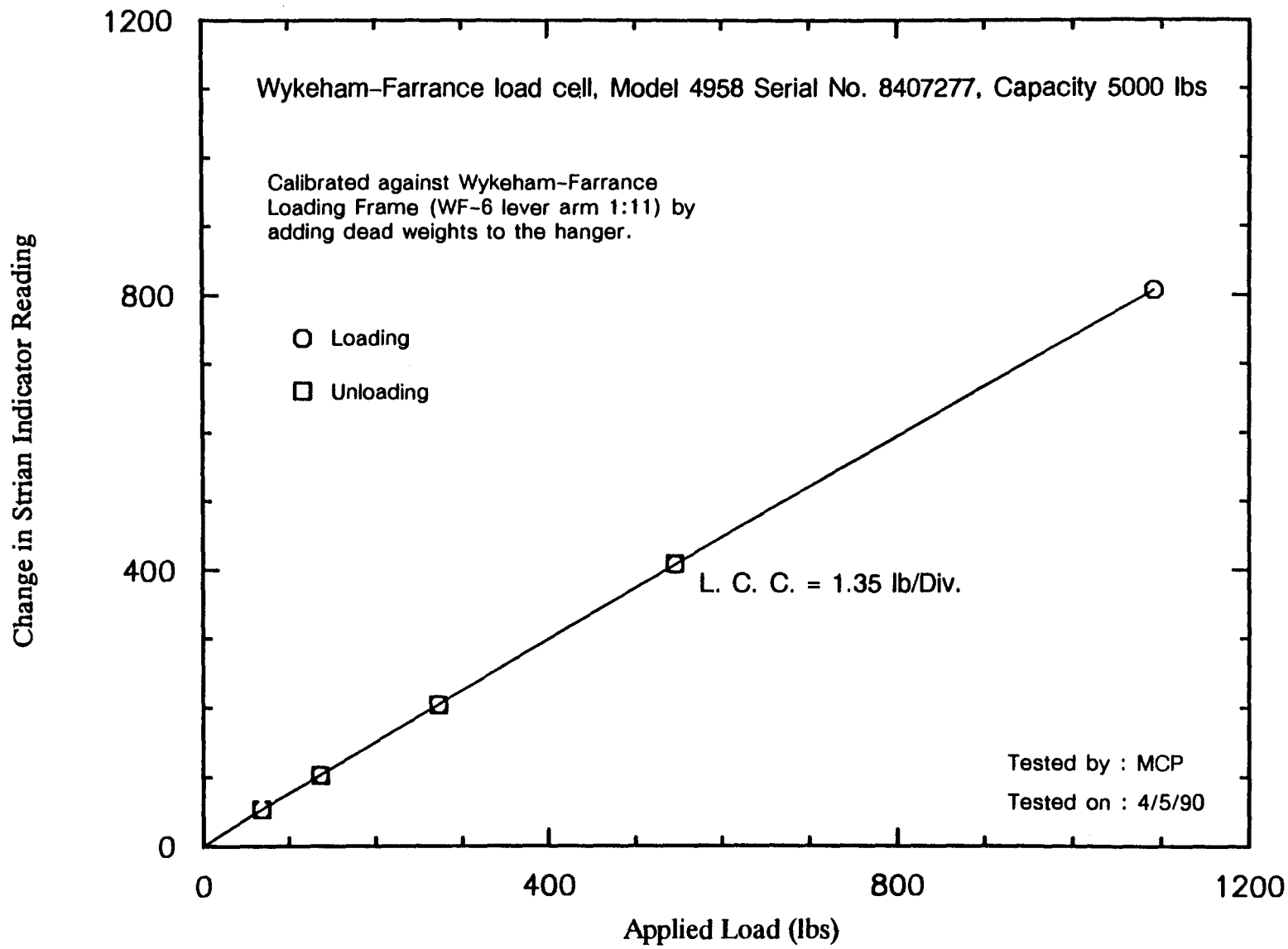


Fig. 7 Calibration of Load Cell, Attached to Rigid Frame Swell Pressure Apparatus

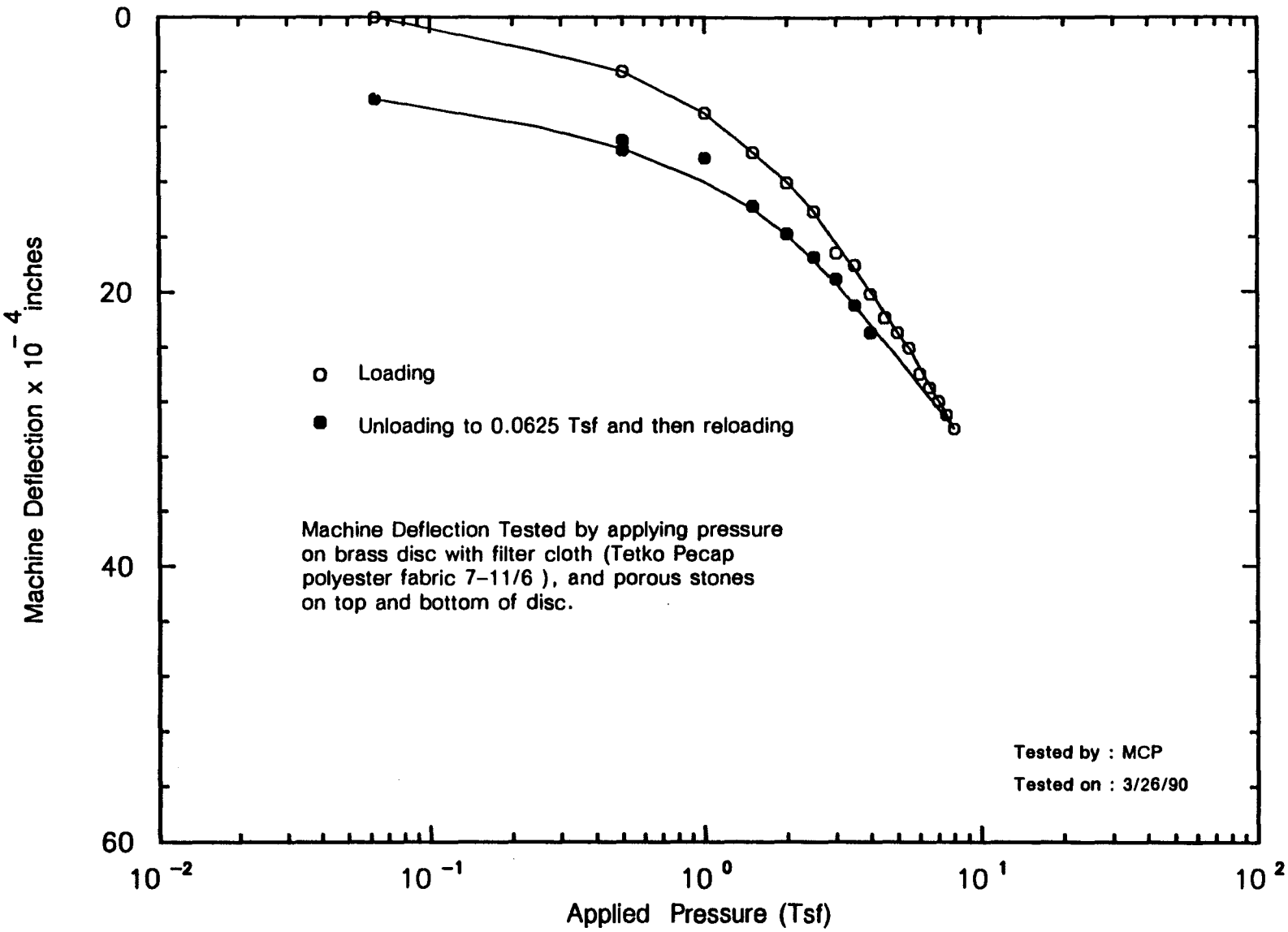


Fig. 8 Machine Deflection for Wykeham-Farrance (WF-6) Loading Frame

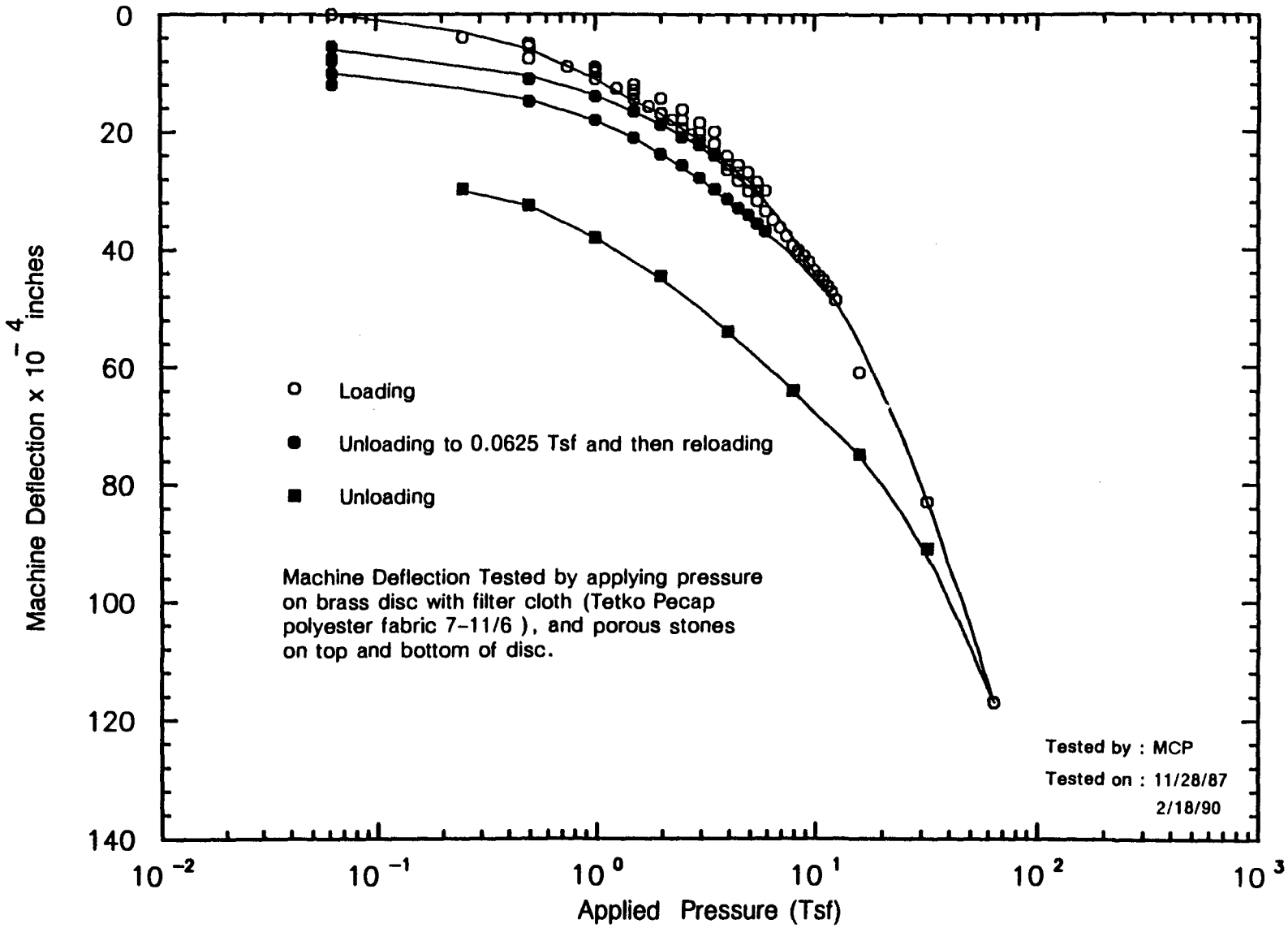


Fig. 9 Machine Deflection for Wykeham-Farrance (WF-7) Loading Frame

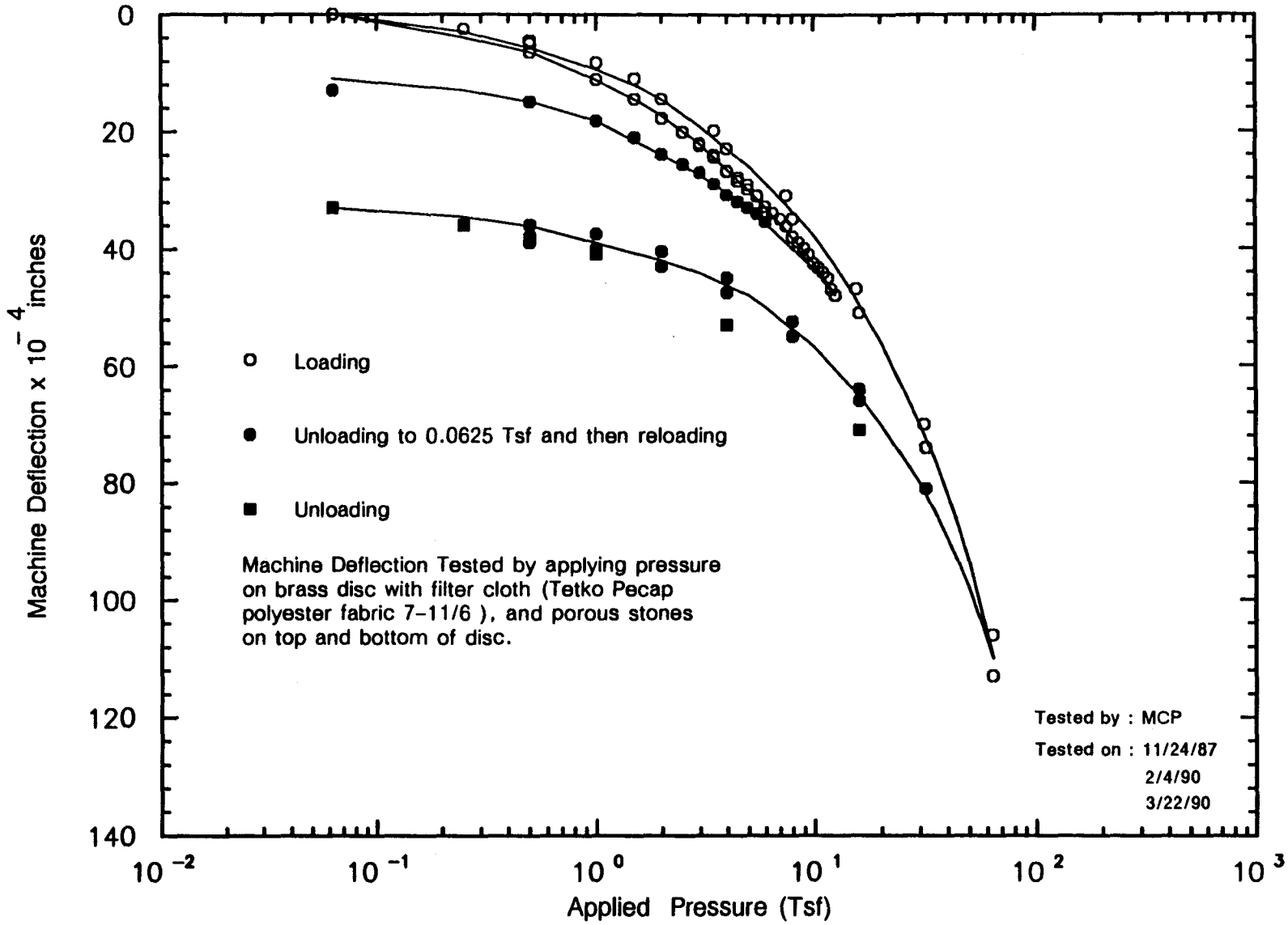


Fig. 10 Machine Deflection for Wykeham-Farrance (WF-8) Loading Frame

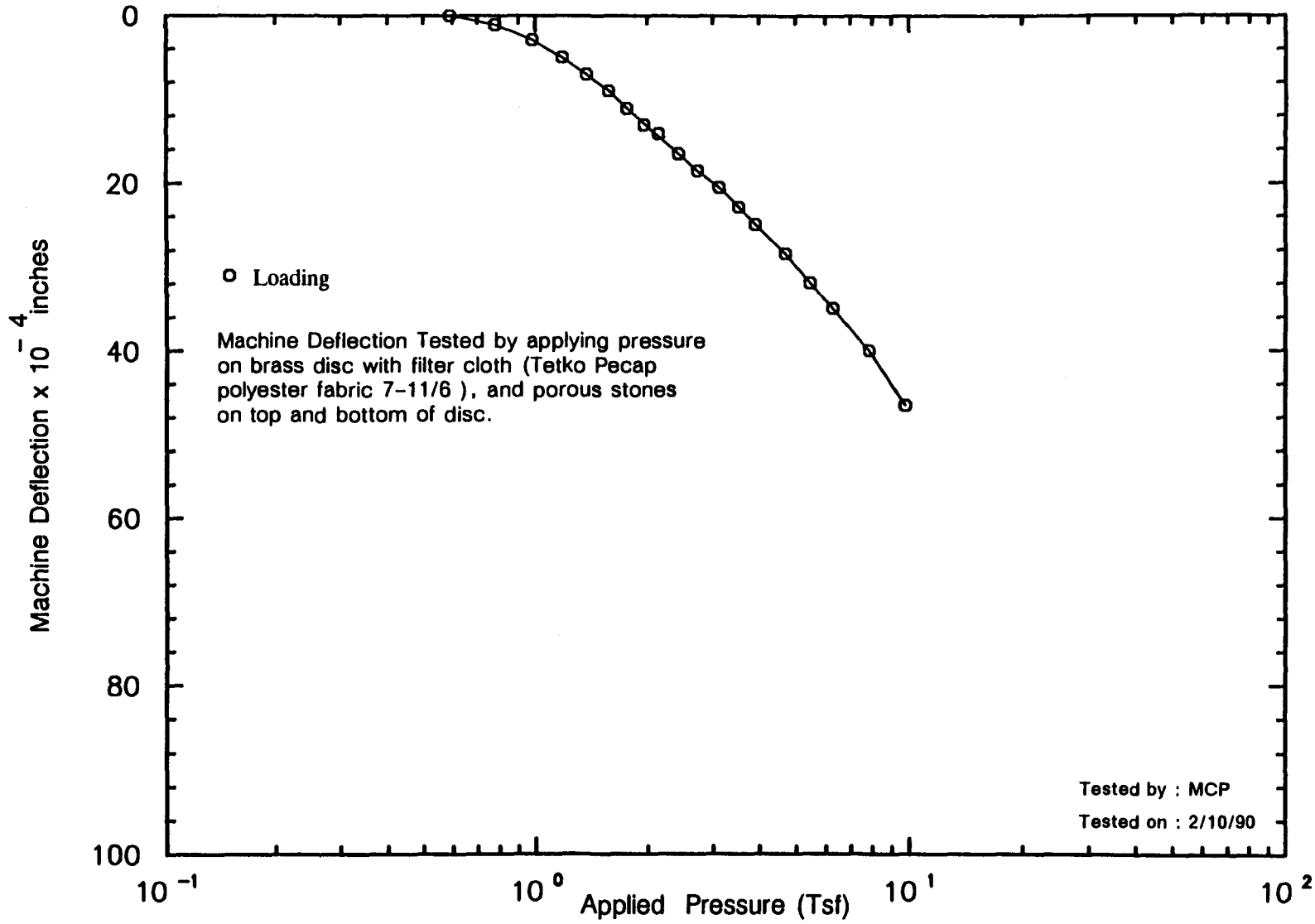


Fig. 11 Machine Deflection for Rigid Frame Swelling Pressure Apparatus

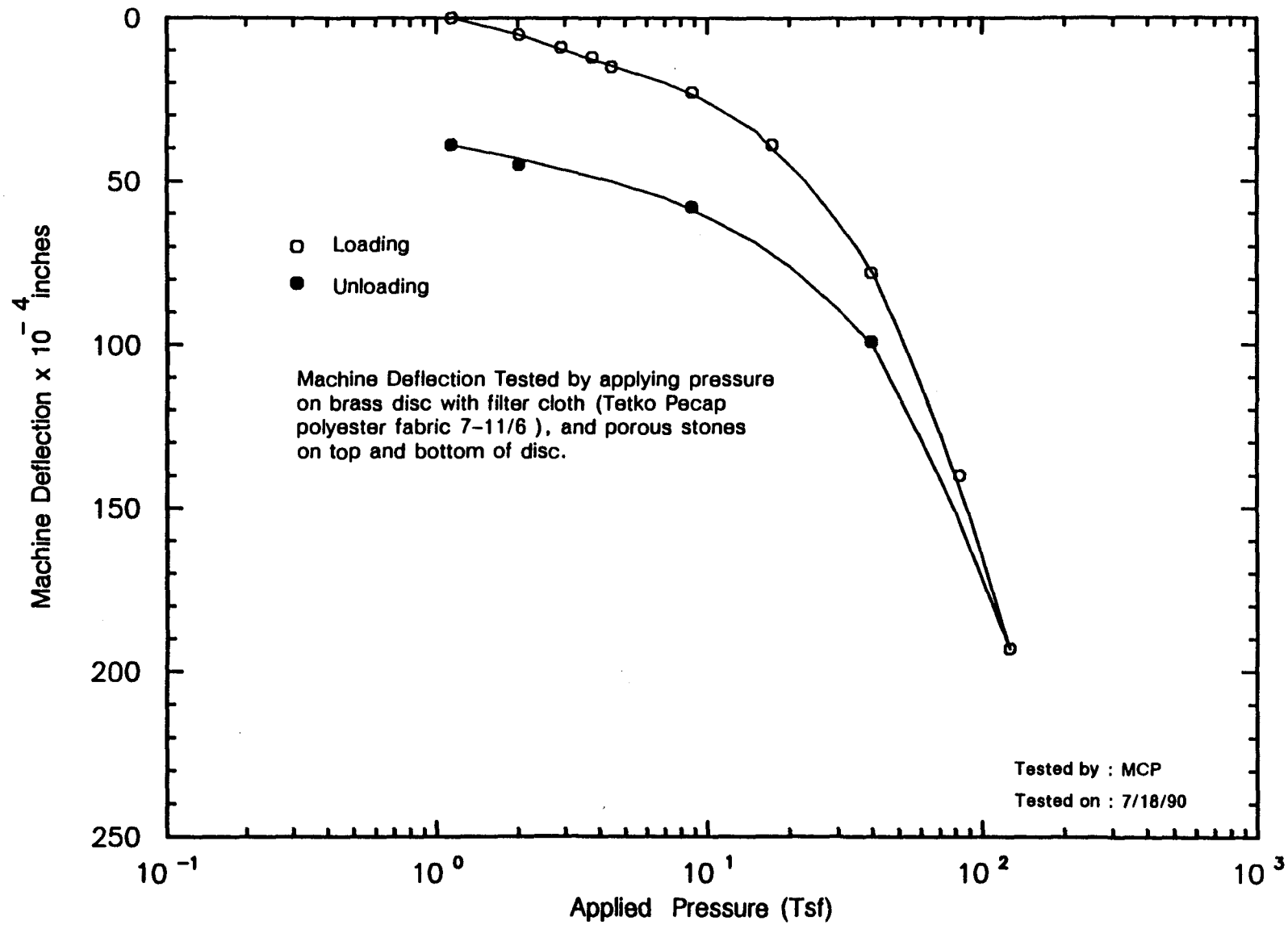


Fig. 12 Machine Deflection for Loading Frame MP-2

APPENDIX CI

Figs. C1 - C14

Stress-Strain Curves
for Unconsolidated Undrained Triaxial
Compression Tests on Eagle Ford shale

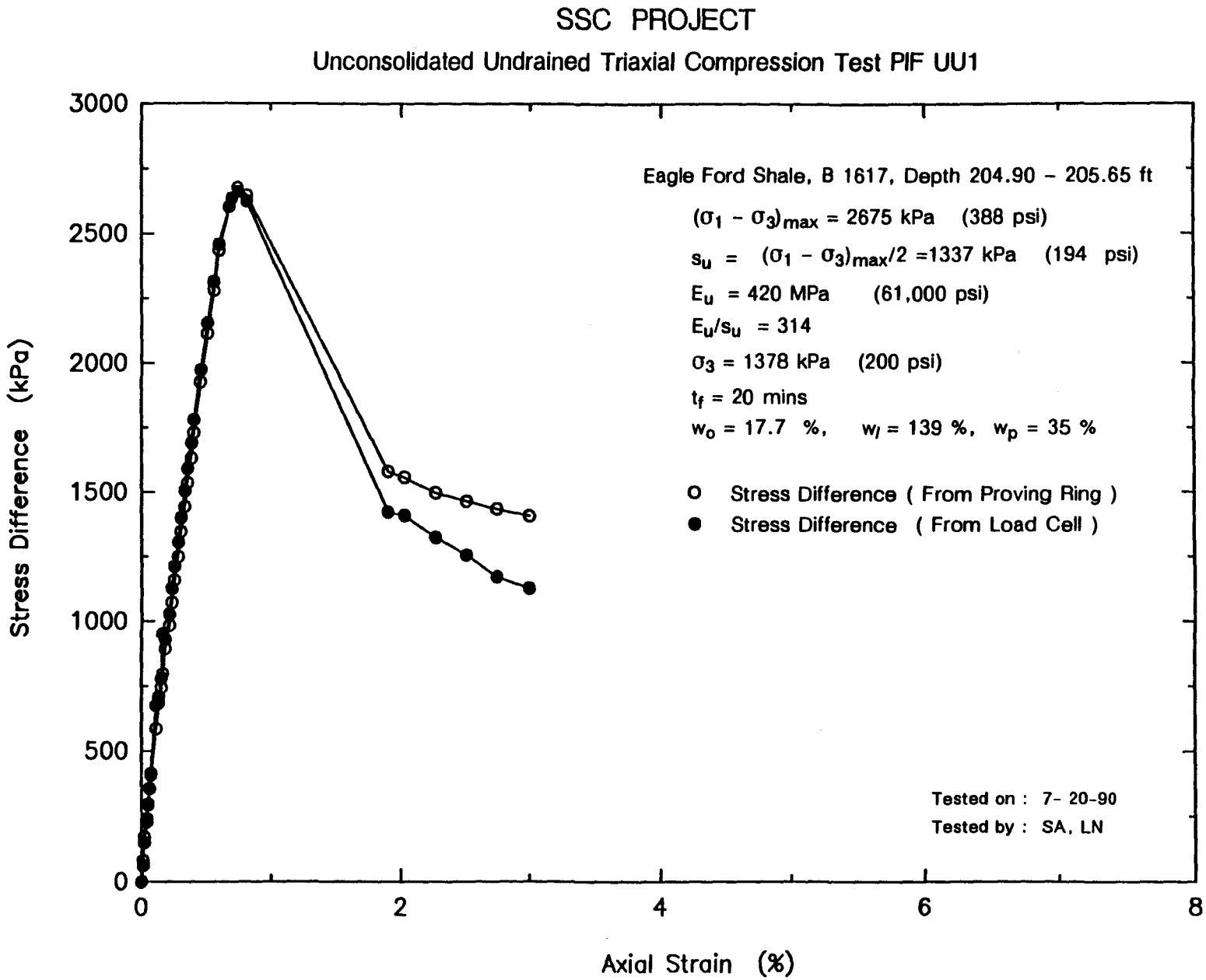


Fig. C1 Stress Difference vs Axial Strain

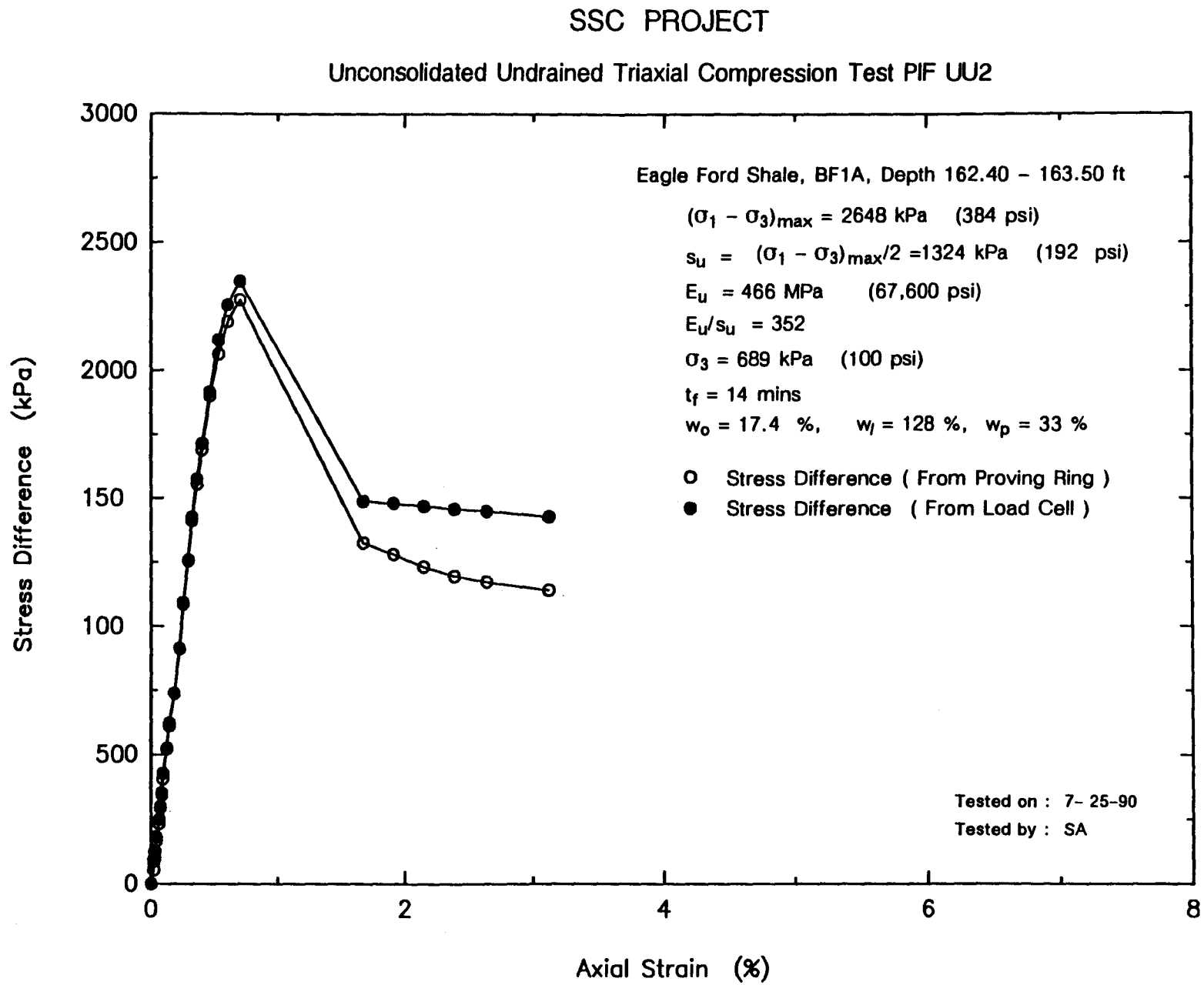


Fig. C2 Stress Difference vs Axial Strain

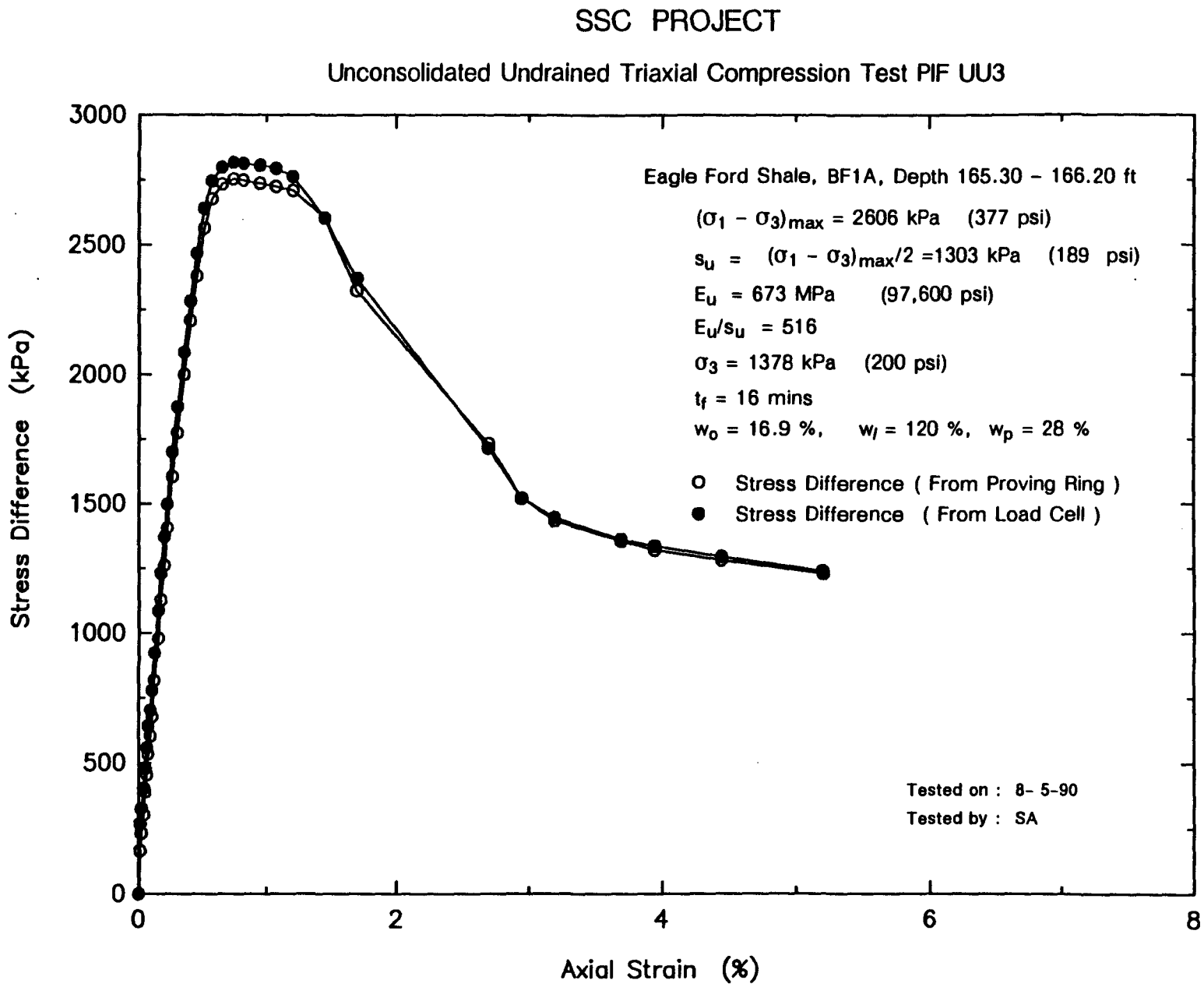


Fig. C3 Stress Difference vs Axial Strain

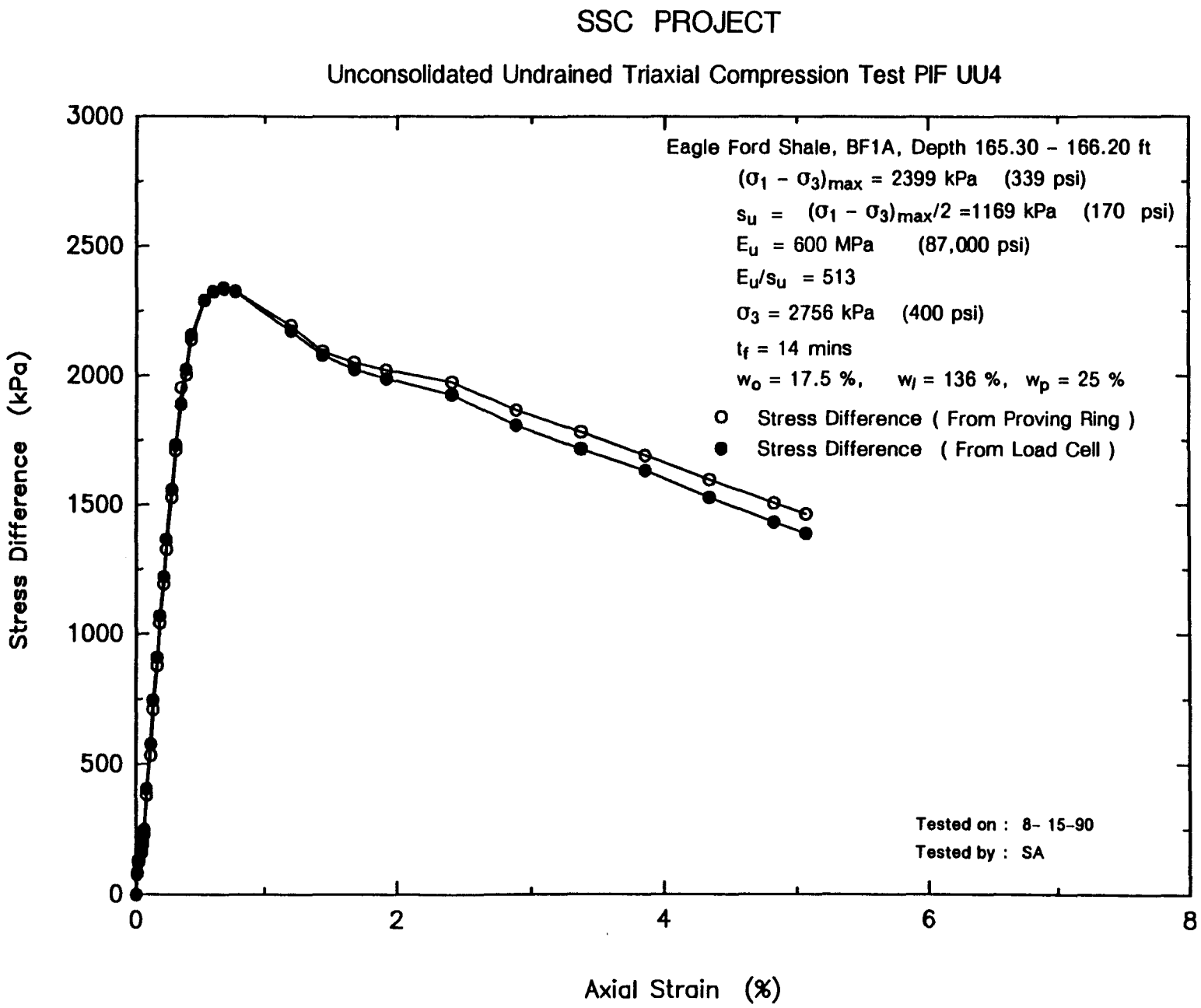


Fig. C4 Stress Difference vs Axial Strain

SSC PROJECT

Unconsolidated Undrained Triaxial Compression Test PIF UU5

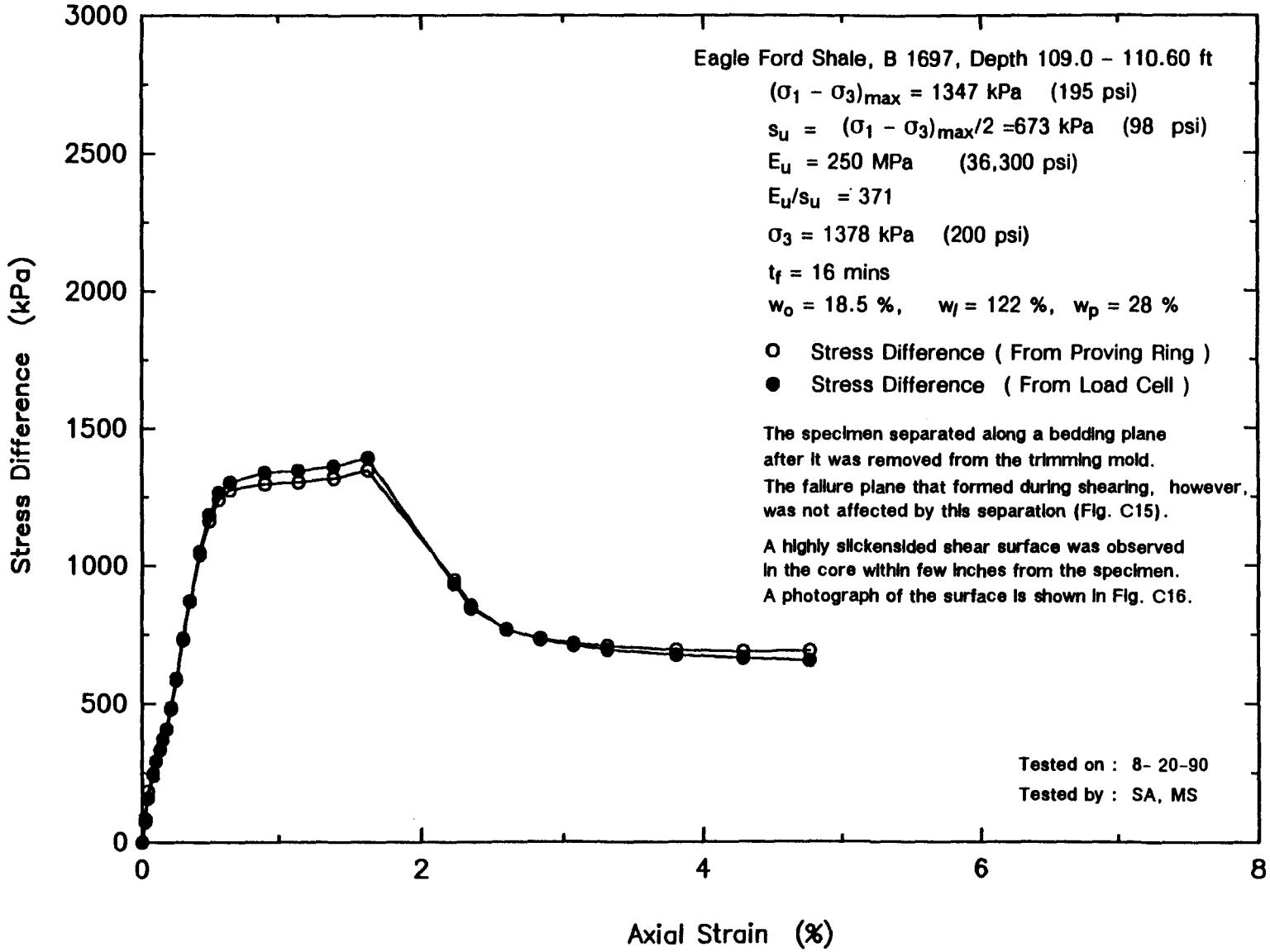


Fig. C5 Stress Difference vs Axial Strain

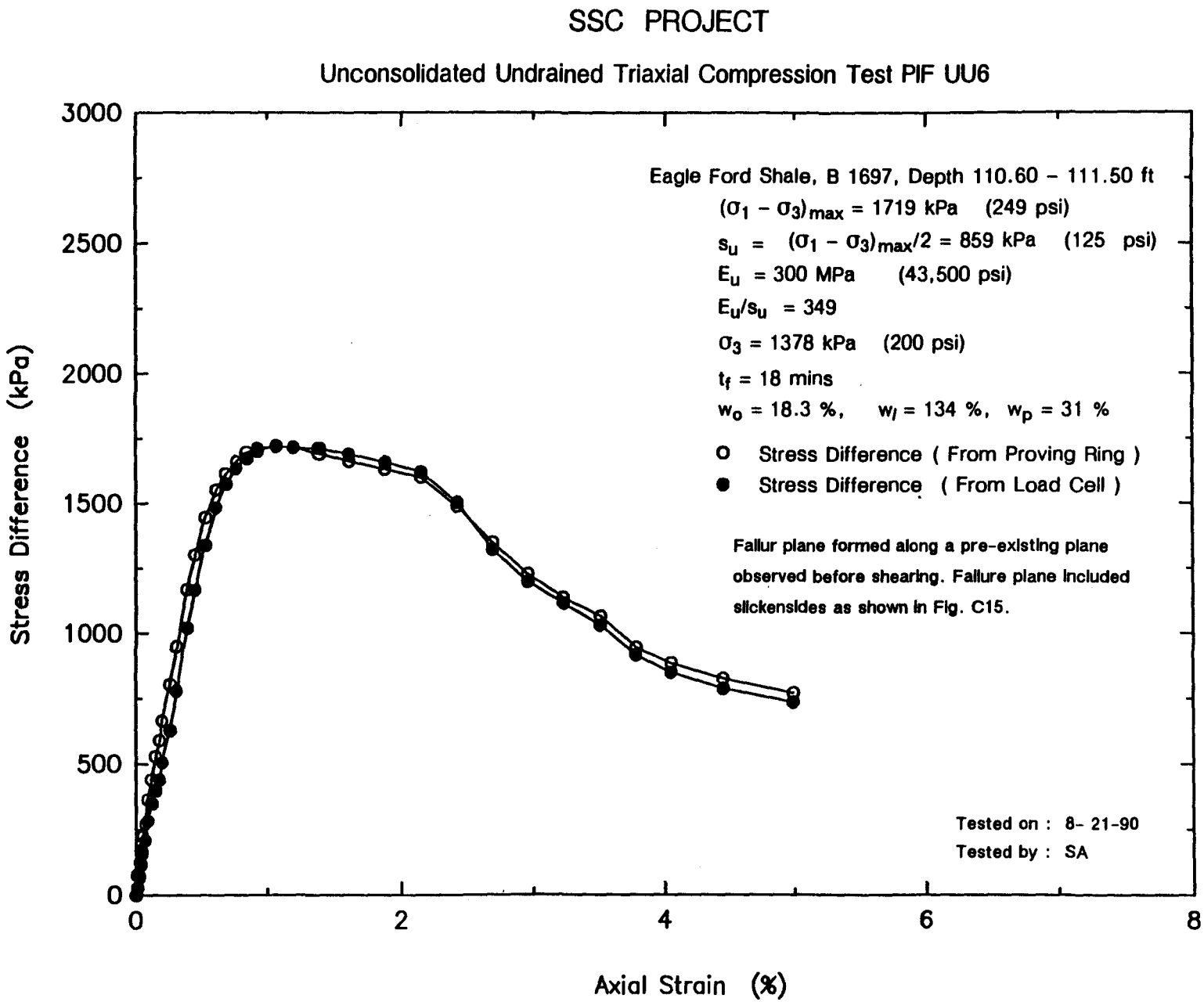


Fig. C6 Stress Difference vs Axial Strain

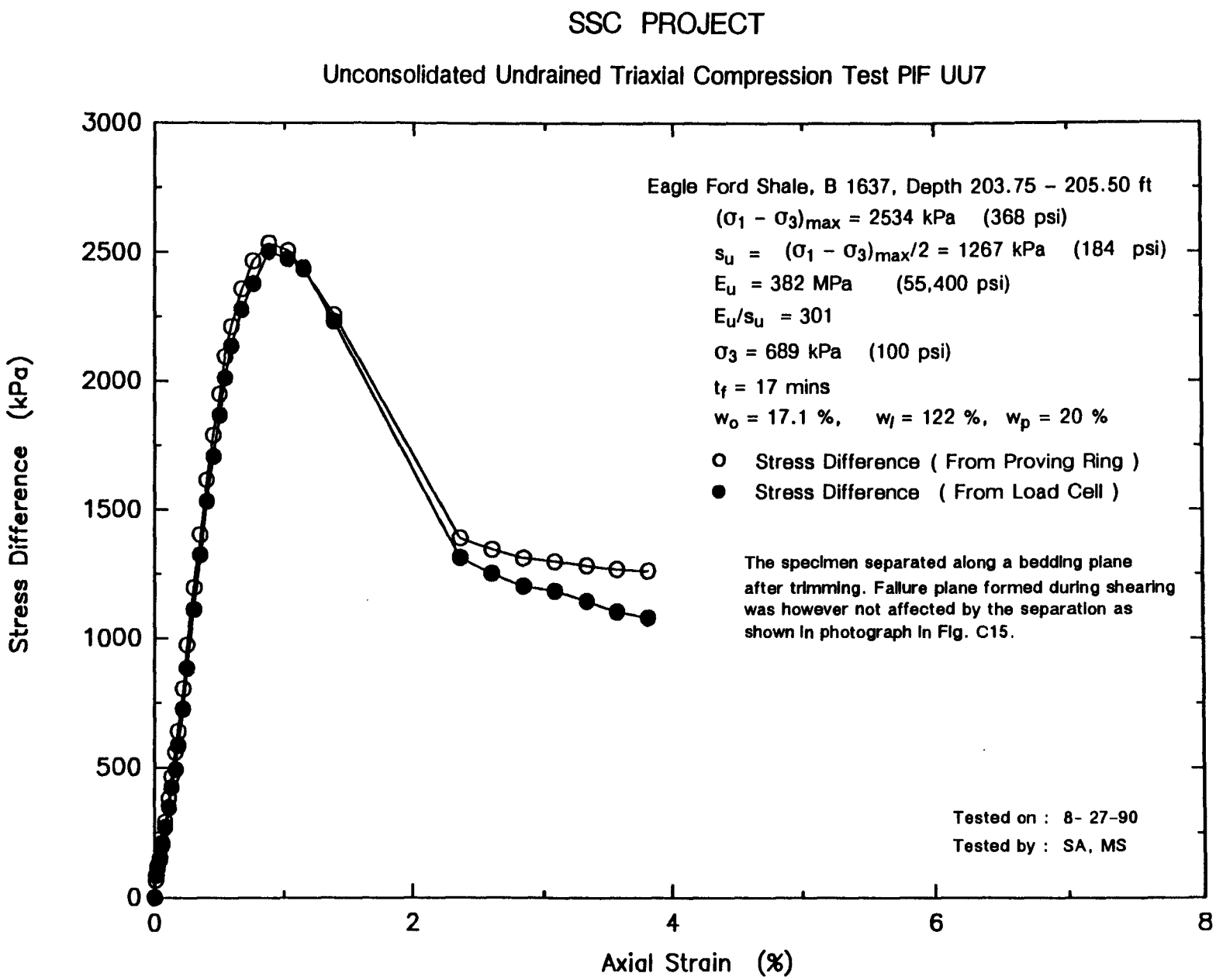


Fig. C7 Stress Difference vs Axial Strain

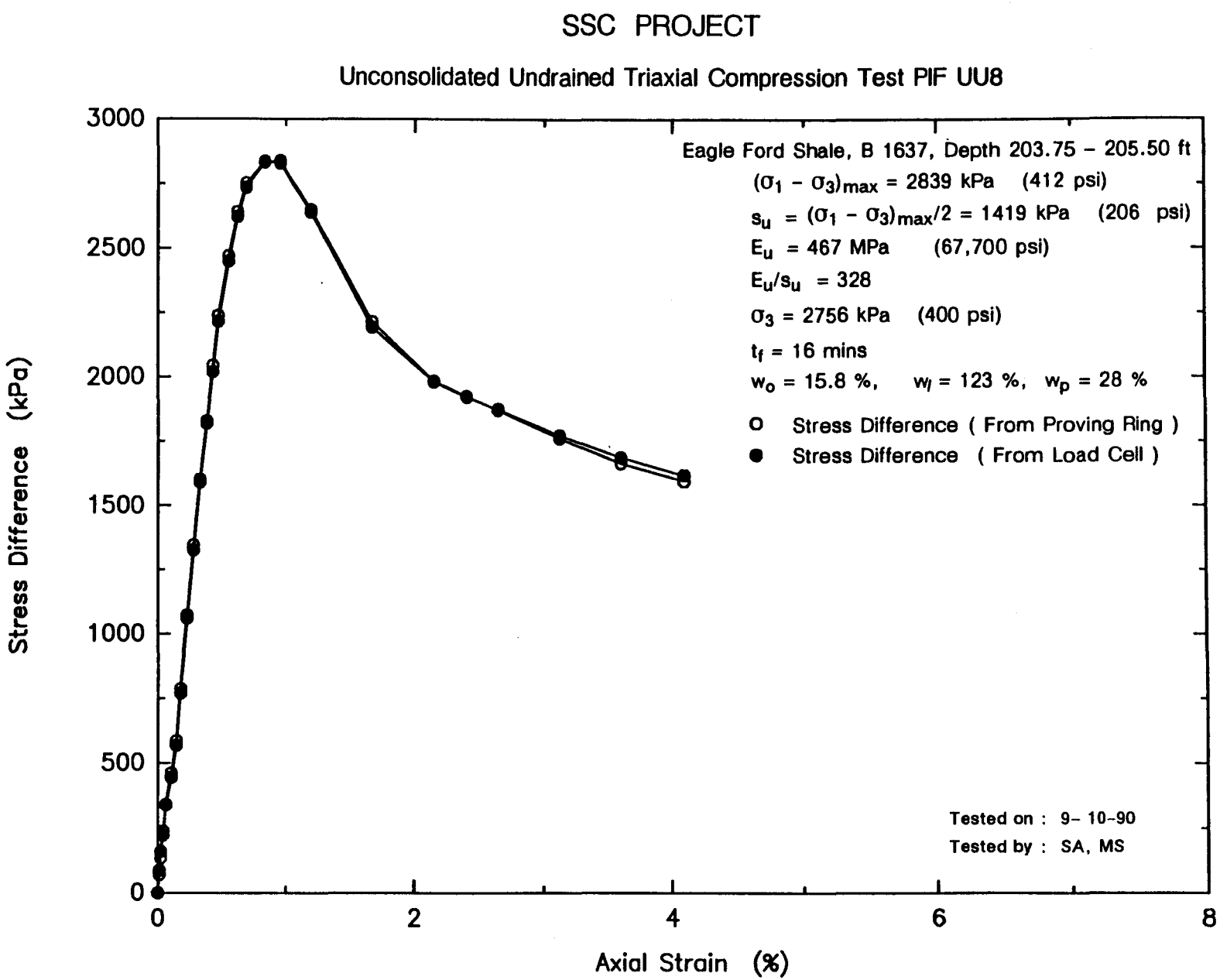


Fig. C8 Stress Difference vs Axial Strain

SSC PROJECT

Unconsolidated Undrained Triaxial Compression Test PIF UU9

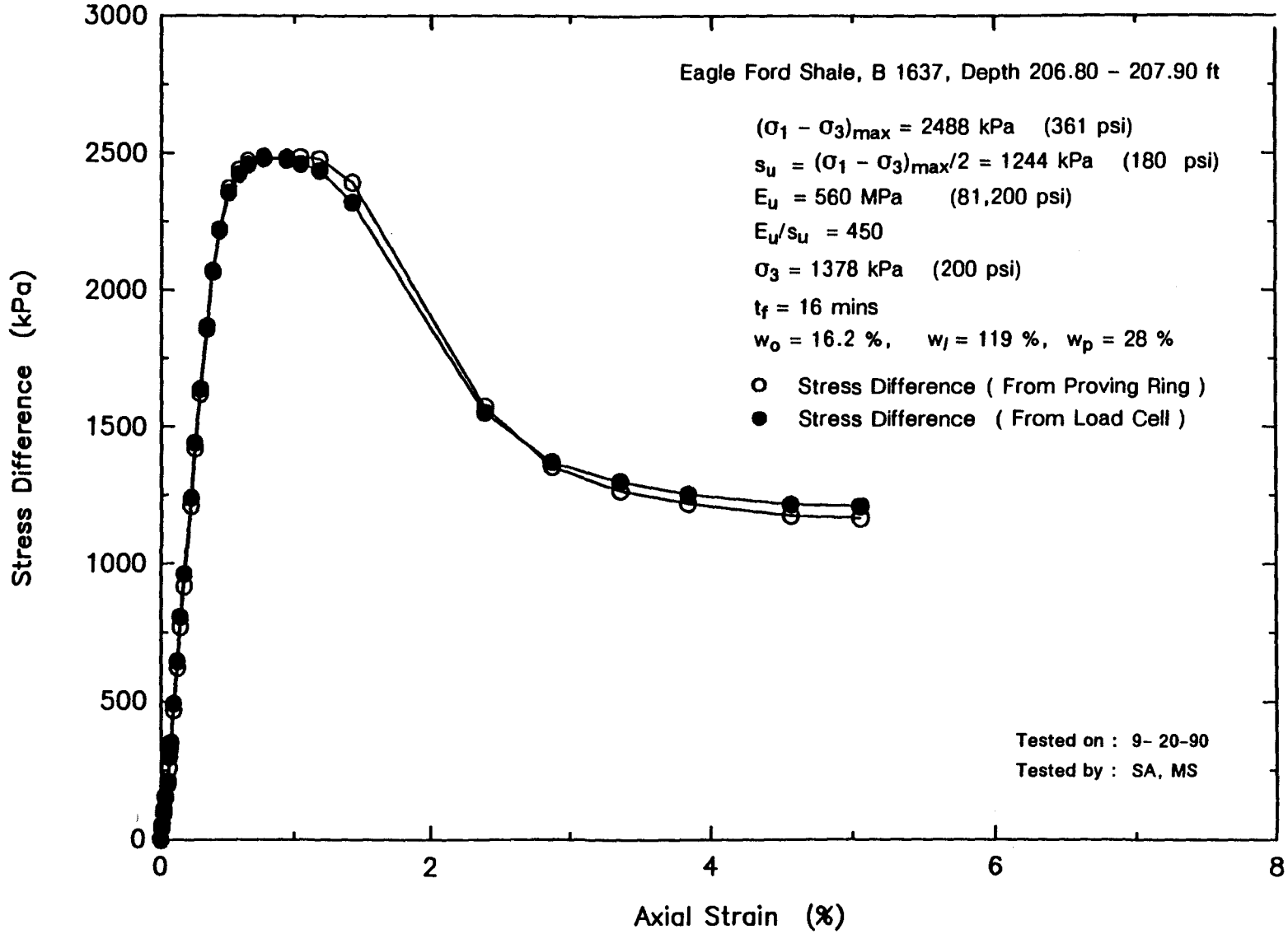


Fig. C9 Stress Difference vs Axial Strain

SSC PROJECT

Unconsolidated Undrained Triaxial Compression Test PIF UU10

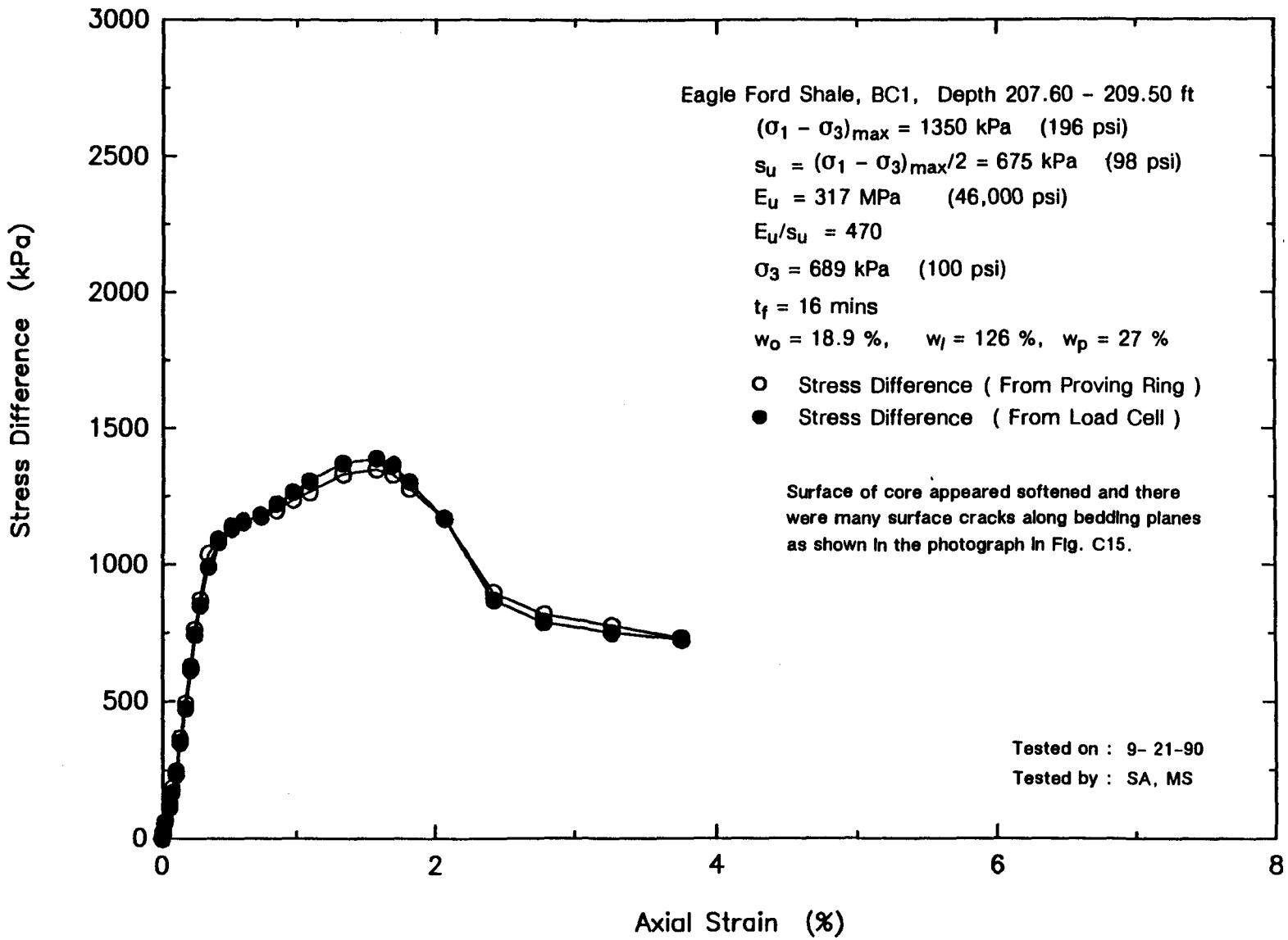


Fig. C10 Stress Difference vs Axial Strain

SSC PROJECT

Unconsolidated Undrained Triaxial Compression Test PIF UU11

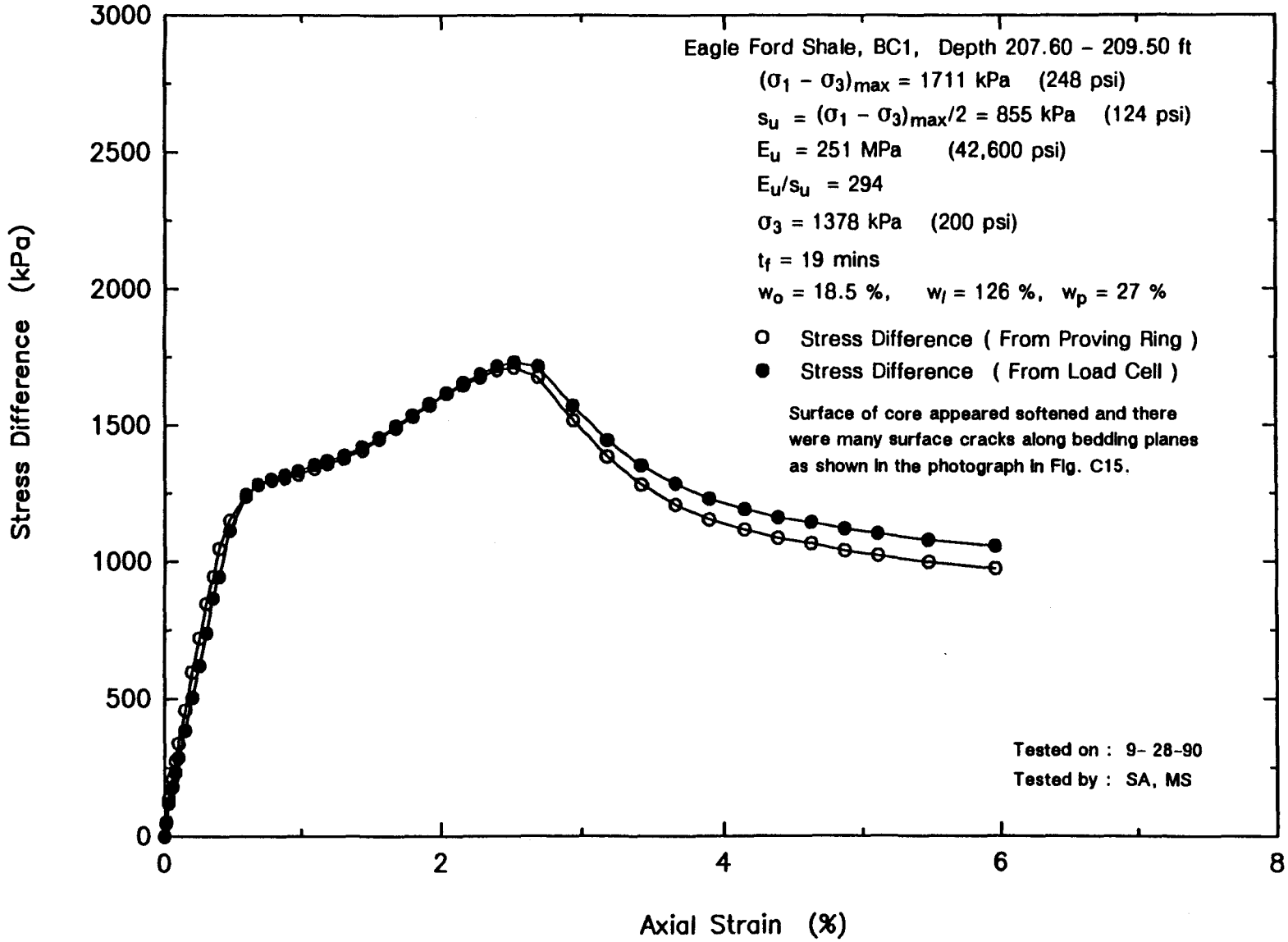


Fig. C11 Stress Difference vs Axial Strain

SSC PROJECT

Unconsolidated Undrained Triaxial Compression Test PIF UU12

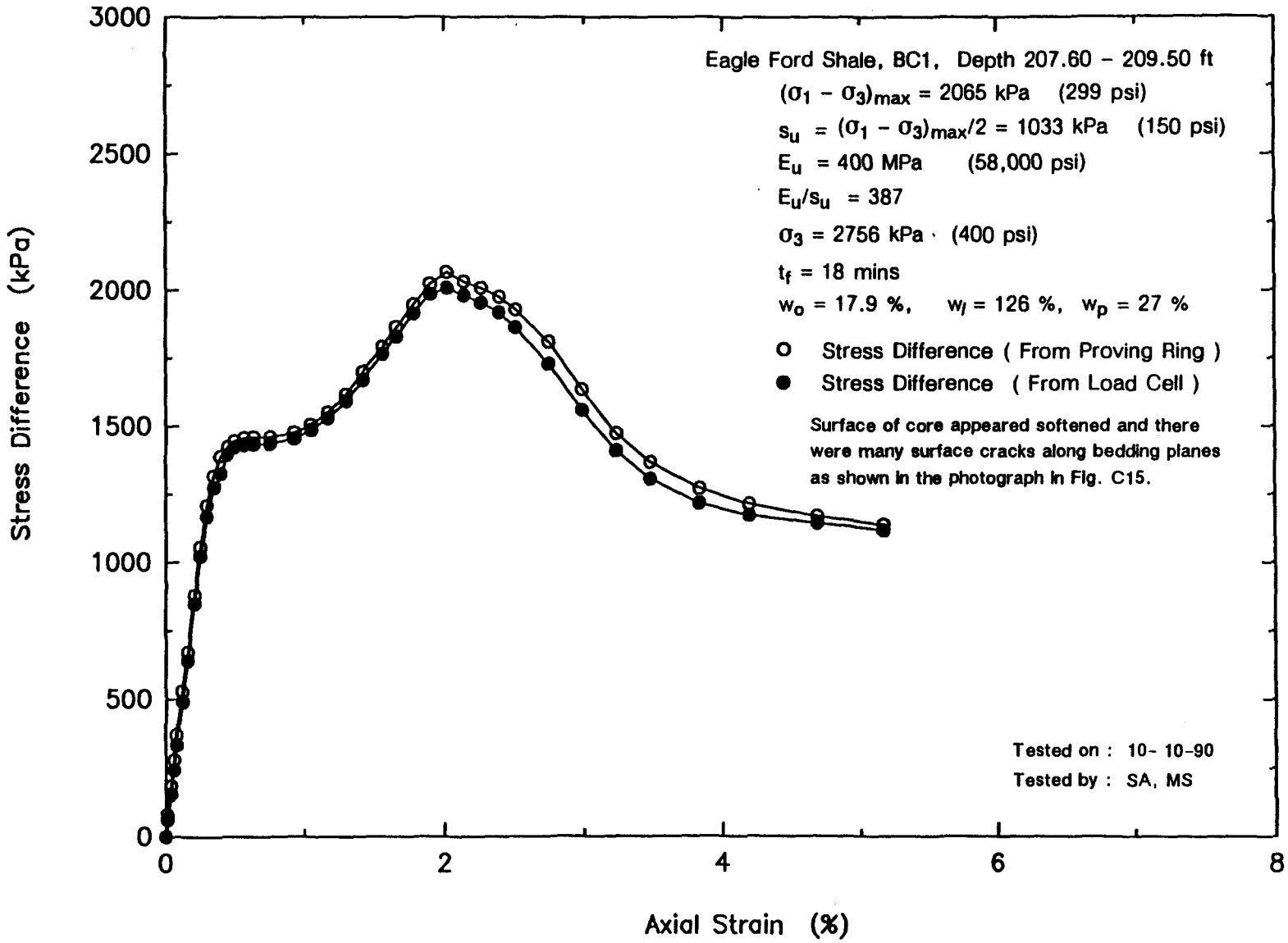


Fig. C12 Stress Difference vs Axial Strain

SSC PROJECT

Unconsolidated Undrained Triaxial Compression Test PIF UU13

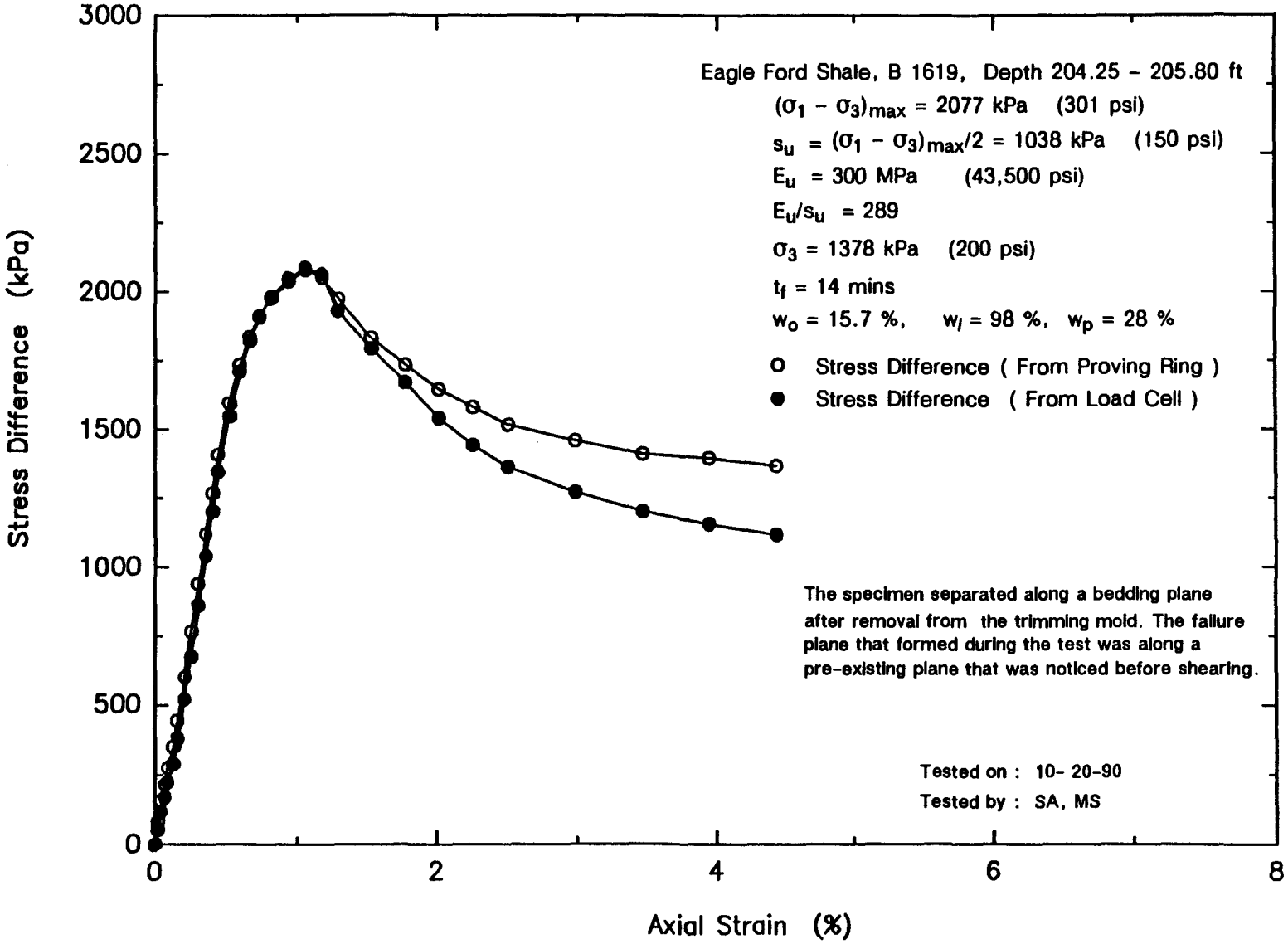


Fig. C13 Stress Difference vs Axial Strain

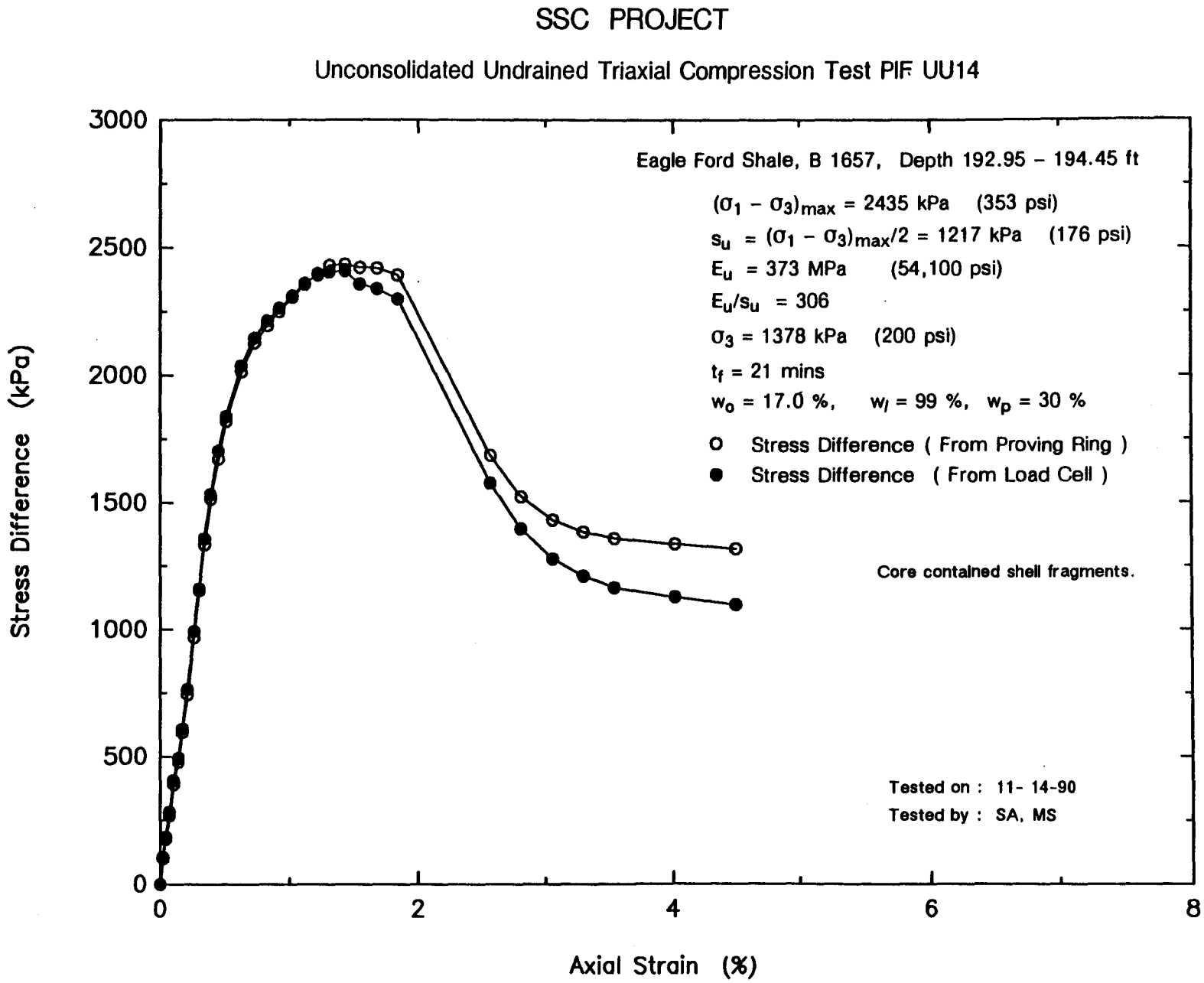
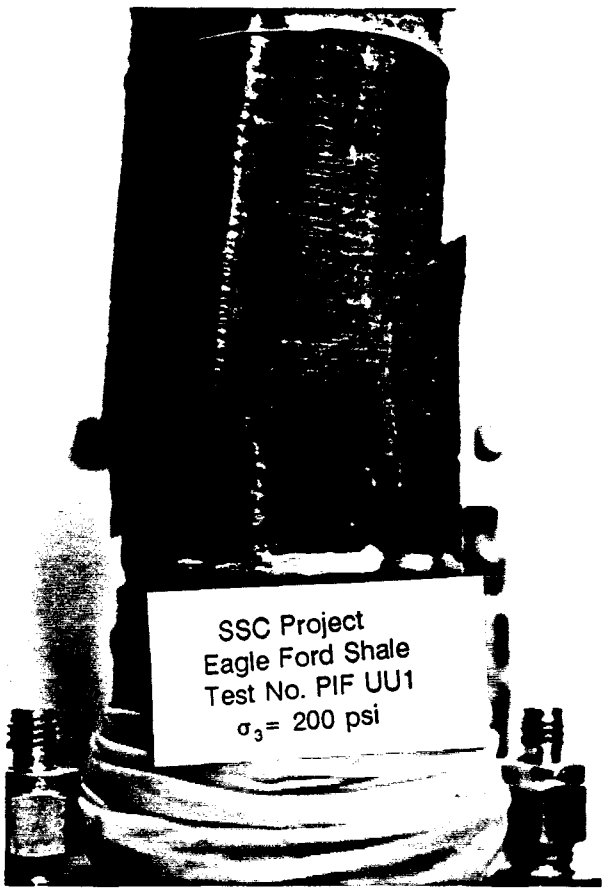
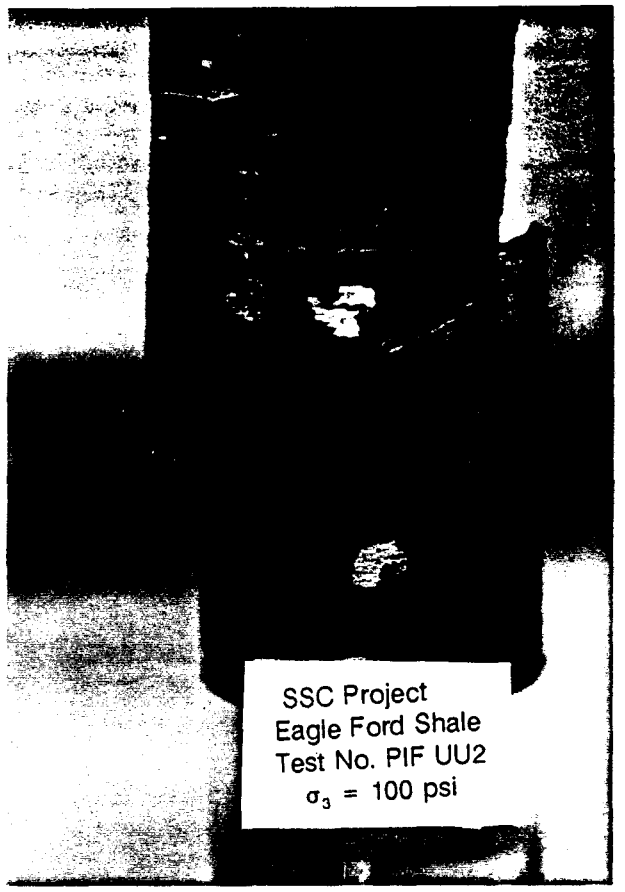


Fig. C14 Stress Difference vs Axial Strain





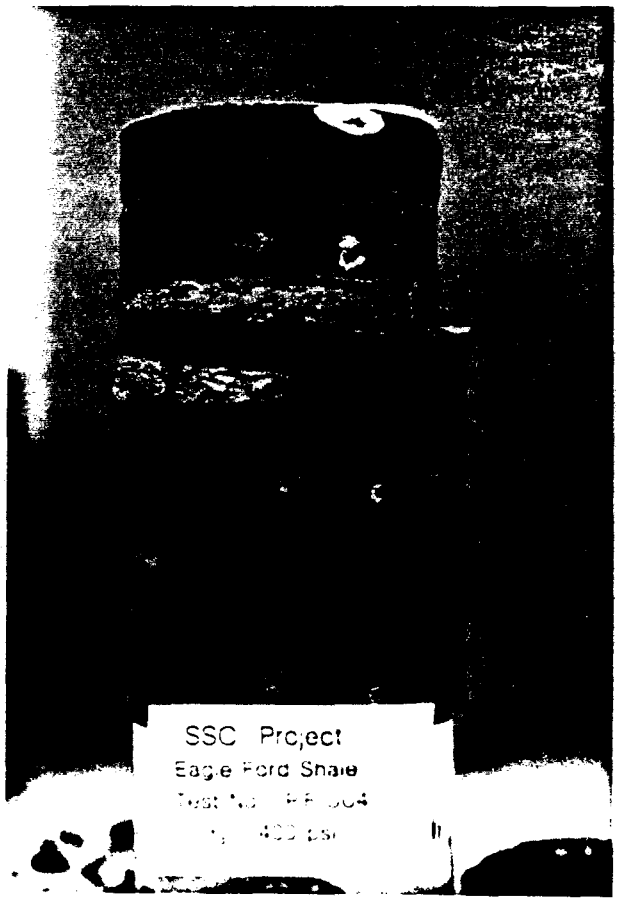
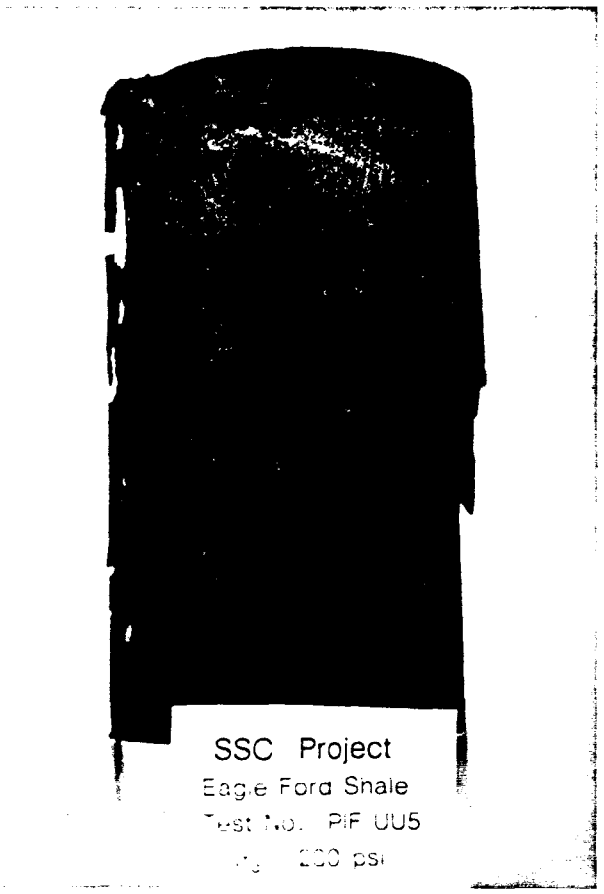


Fig. C15 Photographs of Unconsolidated Undrained Triaxial Compression Specimens at the End of the Tests.



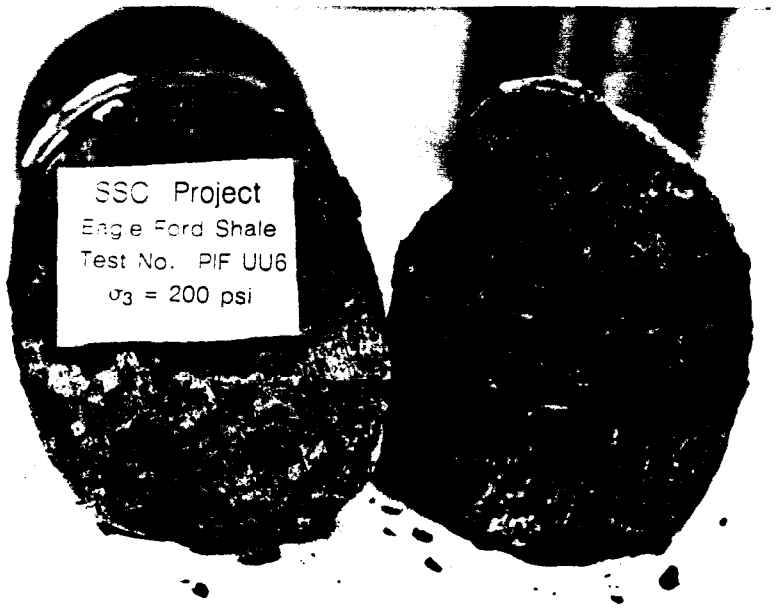


Fig. C15 Photographs of Unconsolidated Undrained Triaxial Compression Specimens at the End of the Tests.

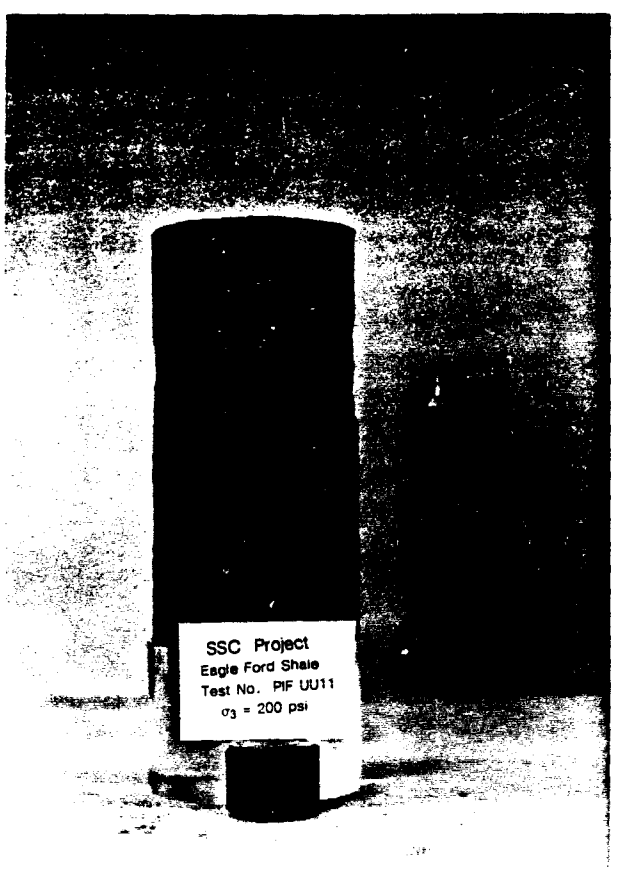
SSC Project
Eagle Ford Shale
Test No. PIF UU7
σ_3 = 100 psi

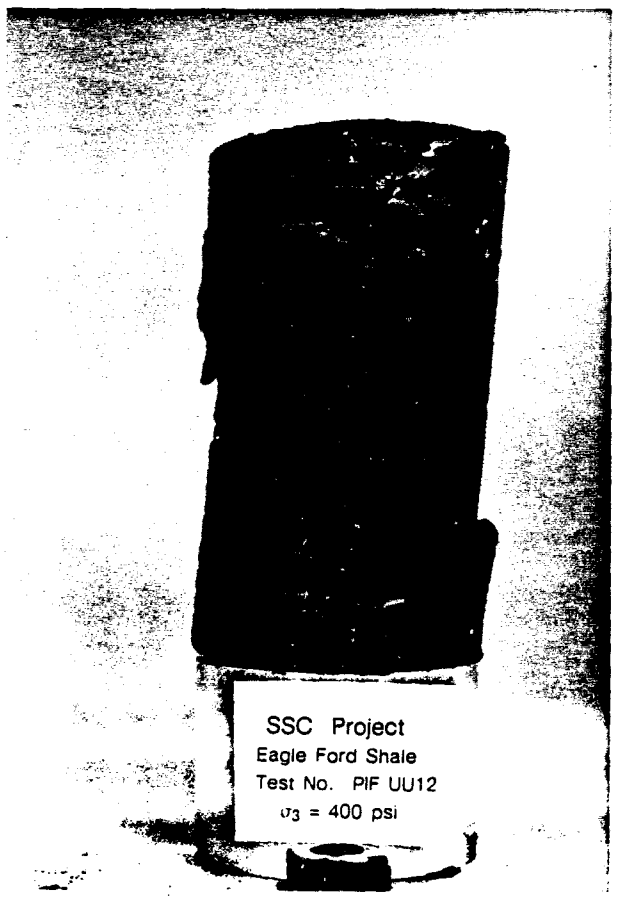
SSC Project
Eagle Ford Shale
Test No. PIF UU8
σ_3 = 400 psi

SSC Project
Eagle Ford Shale
Test No. PIF UU8
σ_3 = 400 psi

SSC Project
Eagle Ford Shale
Test No. PIF UU8
σ_3 = 400 psi

Fig. C15 Photographs of Unconsolidated Undrained Triaxial Compression Specimens at the End of the Tests.





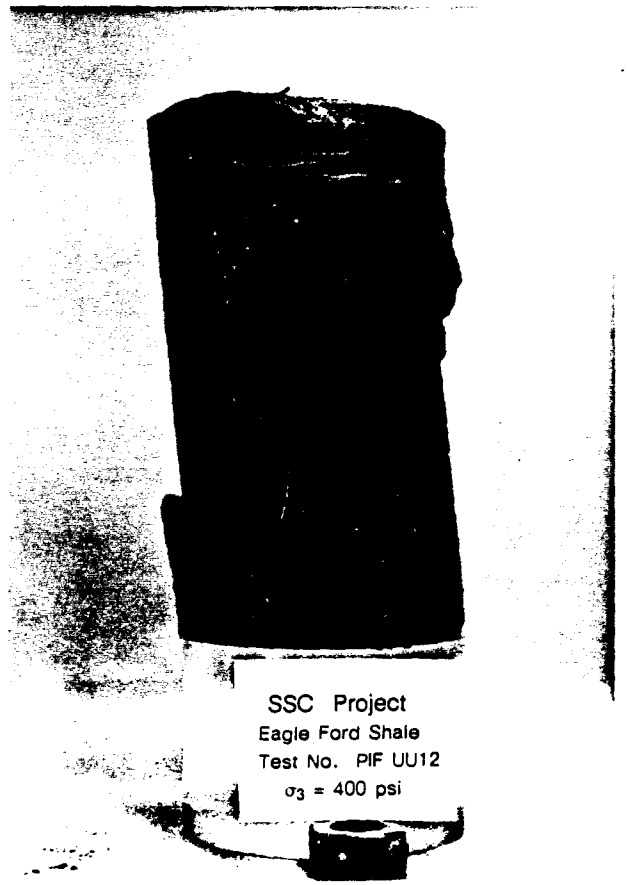
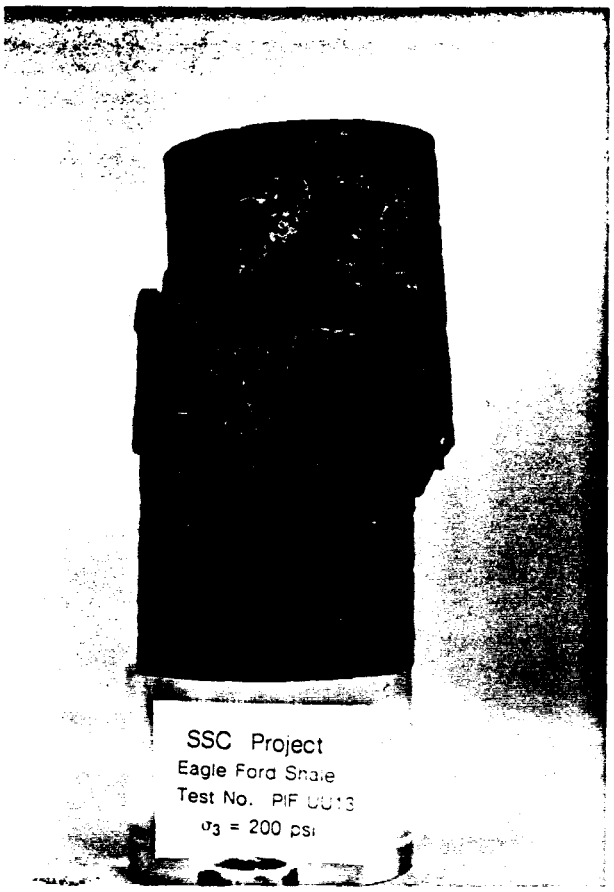
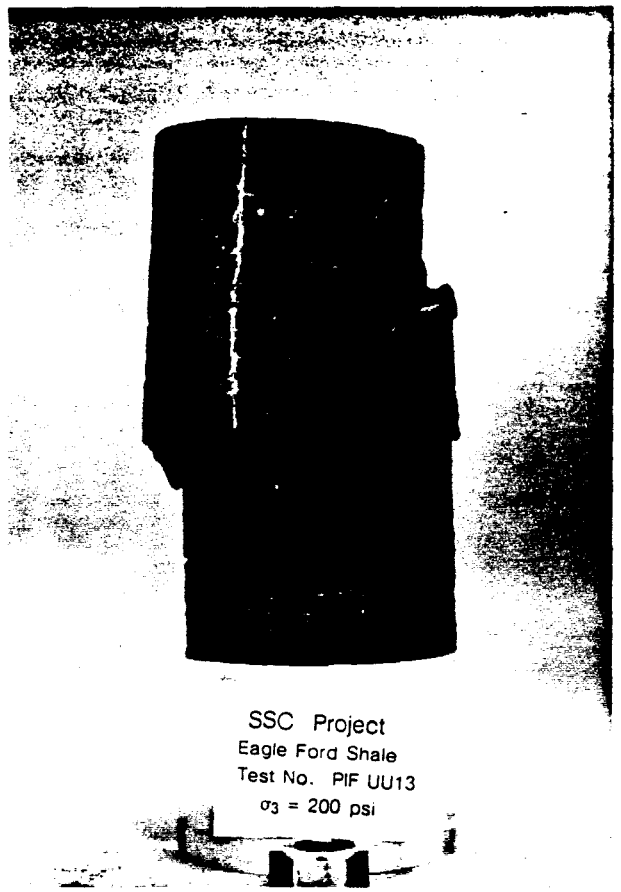
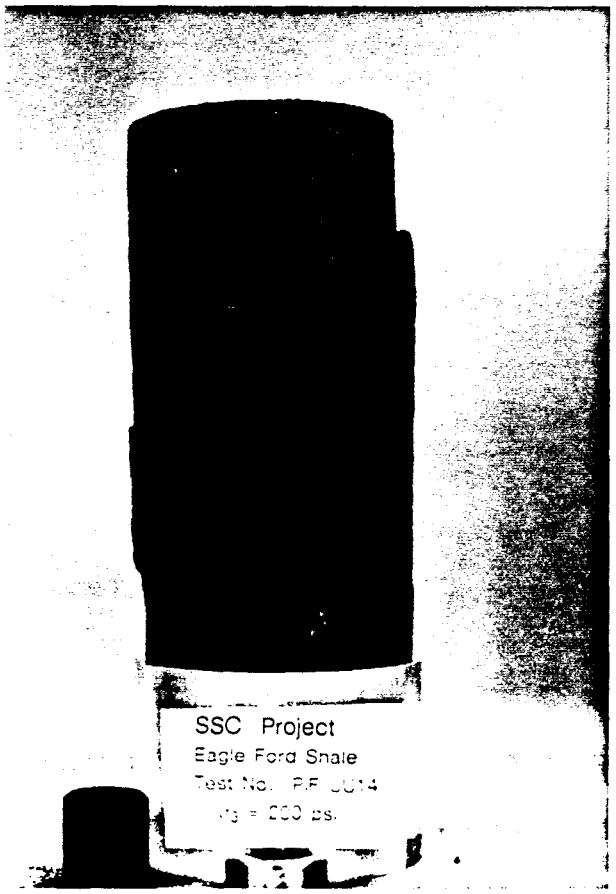


Fig. C15 Photographs of Unconsolidated Undrained Triaxial Compression Specimens at the End of the Tests.







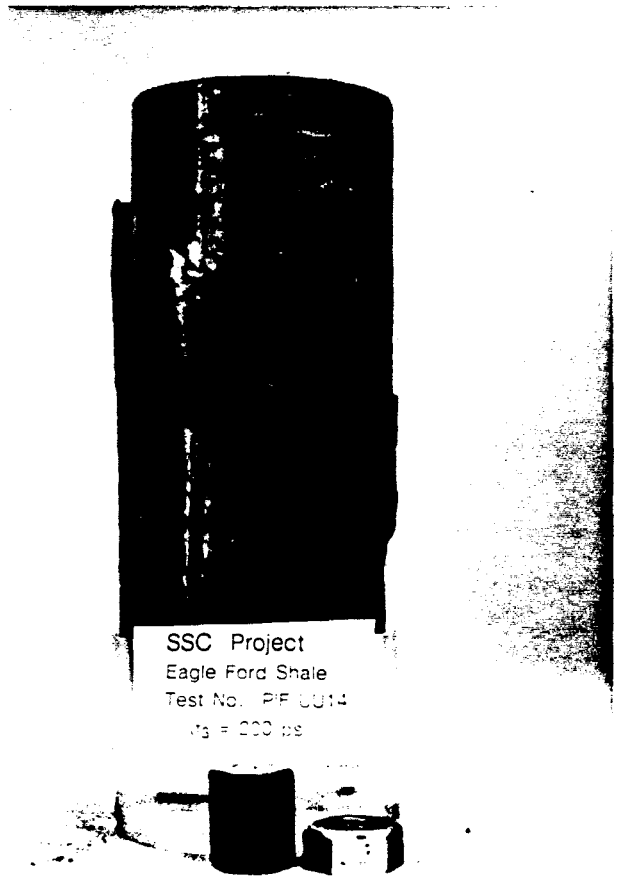
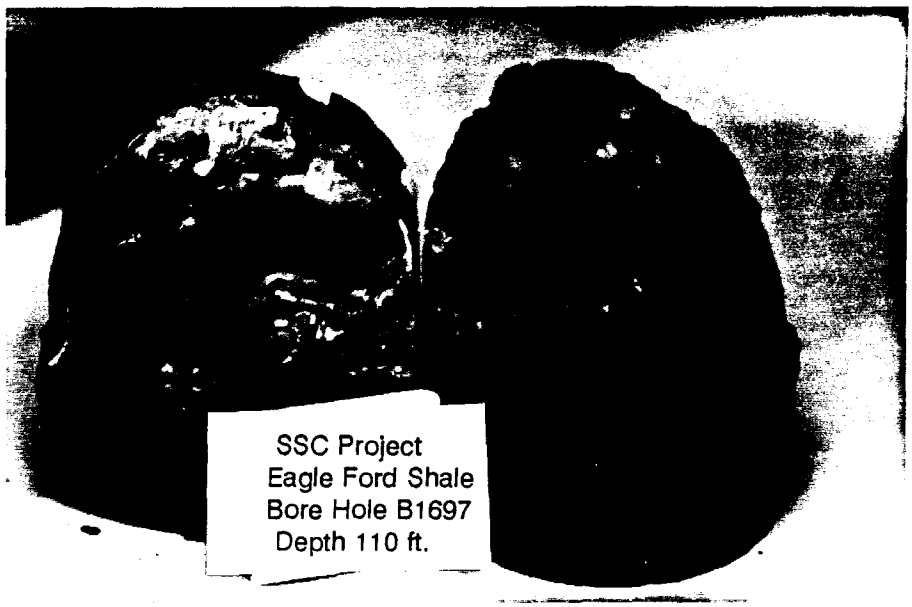


Fig. C15 Photographs of Unconsolidated Undrained Triaxial Compression Specimens at the End of the Tests.



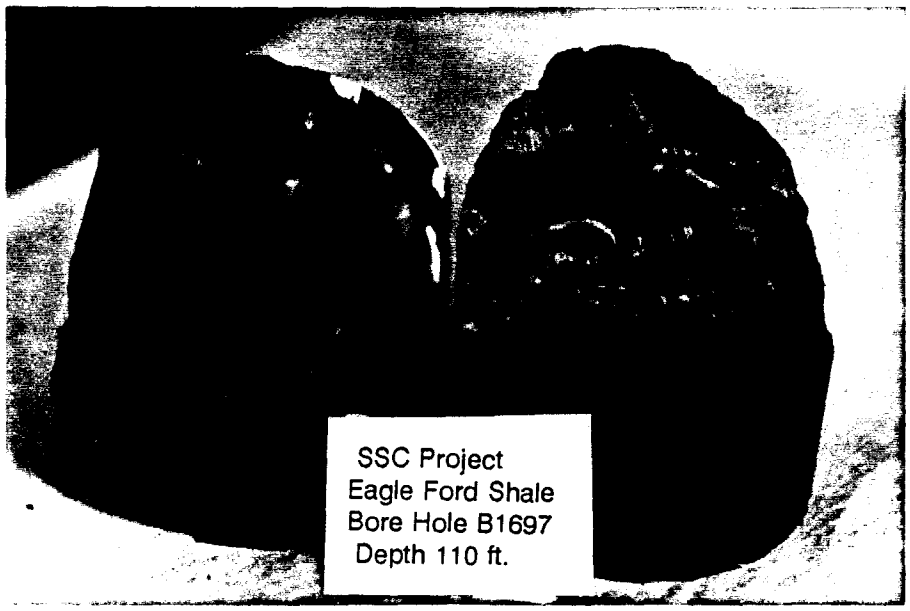


Fig. C16 Photograph of a highly slickensided shear surface, Eagle Ford shale, Bore Hole B1697, Depth: 109.00-110.60 ft

APPENDIX DI

Figs. D1 - D9

Void Ratio-Log Pressure Relationships
and Time-rate of Swelling Pressure Development
for Oedometer Tests on Eagle Ford shale

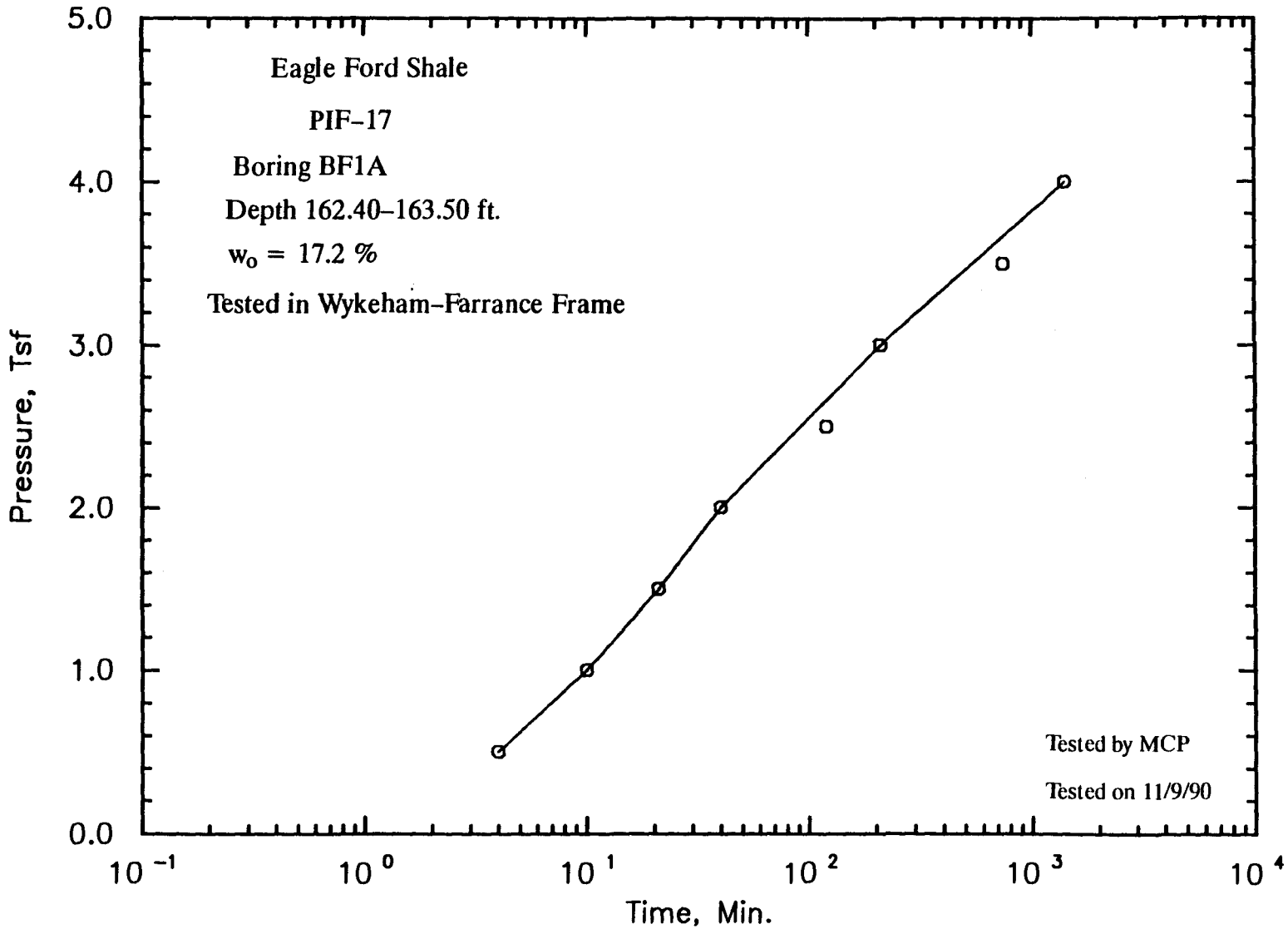


Fig. D1a Time-Rate of Swelling Pressure Development

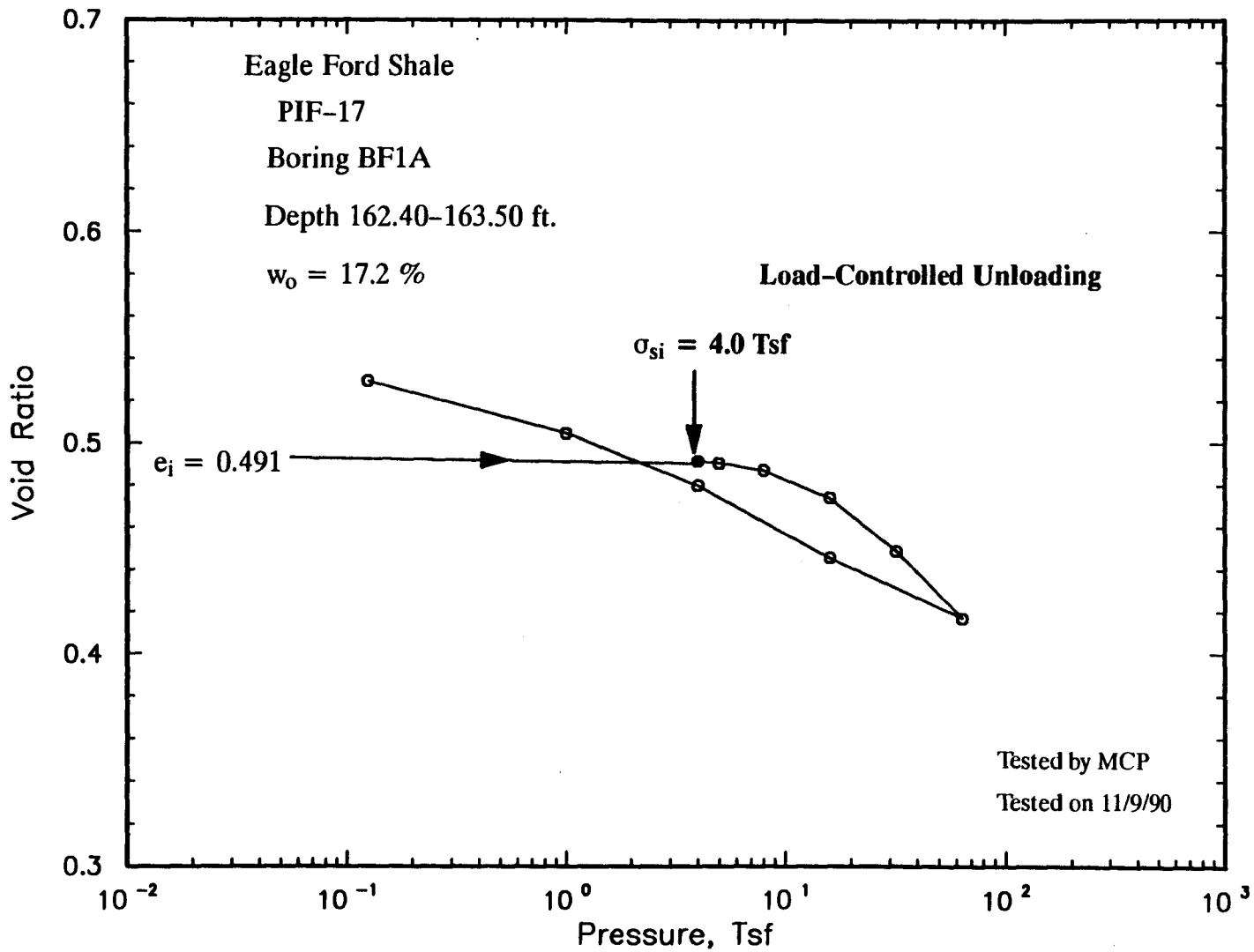


Fig. D1b Void Ratio - Log Pressure Relationship

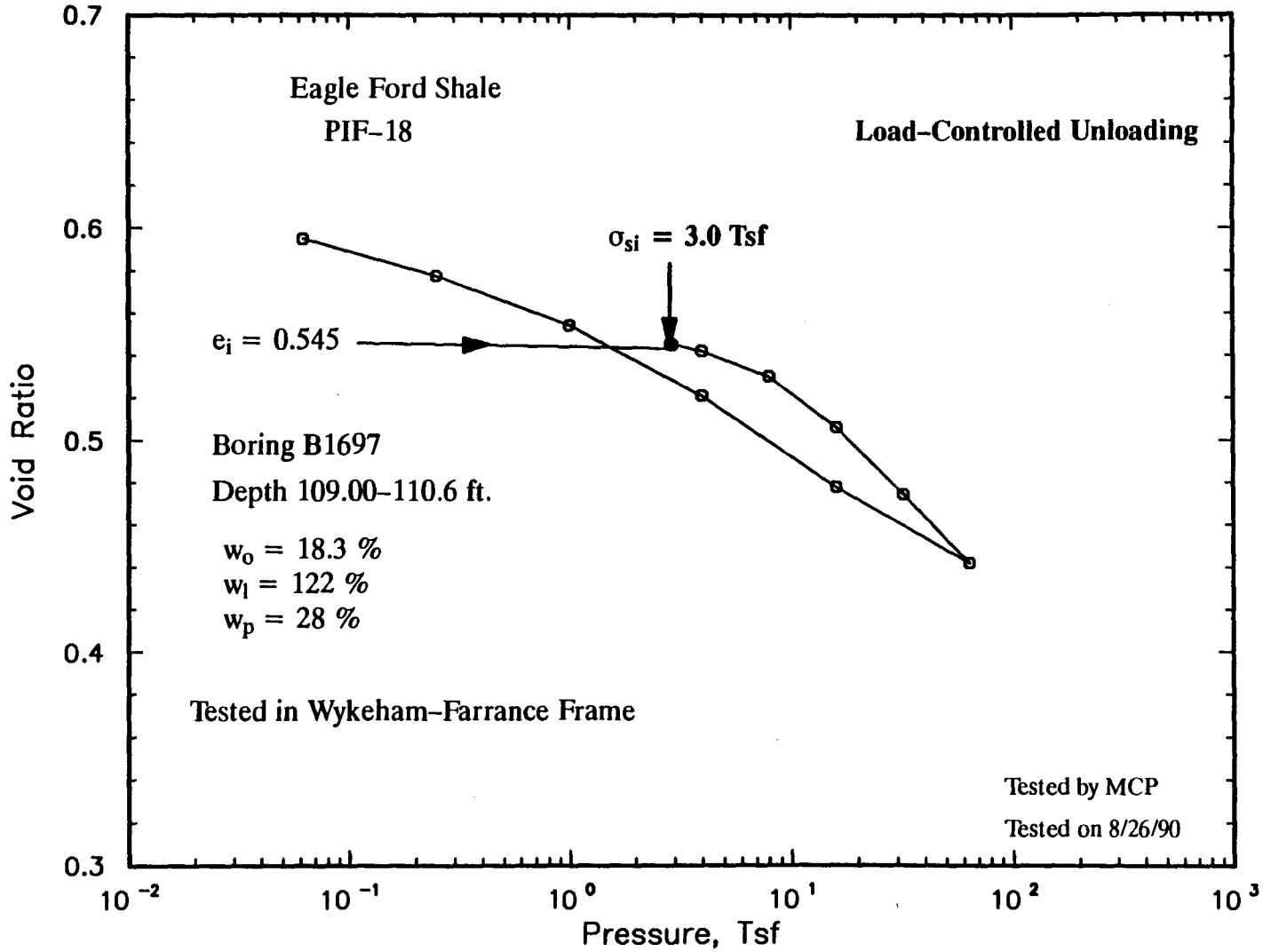


Fig. D2 Void Ratio - Log Pressure Relationship

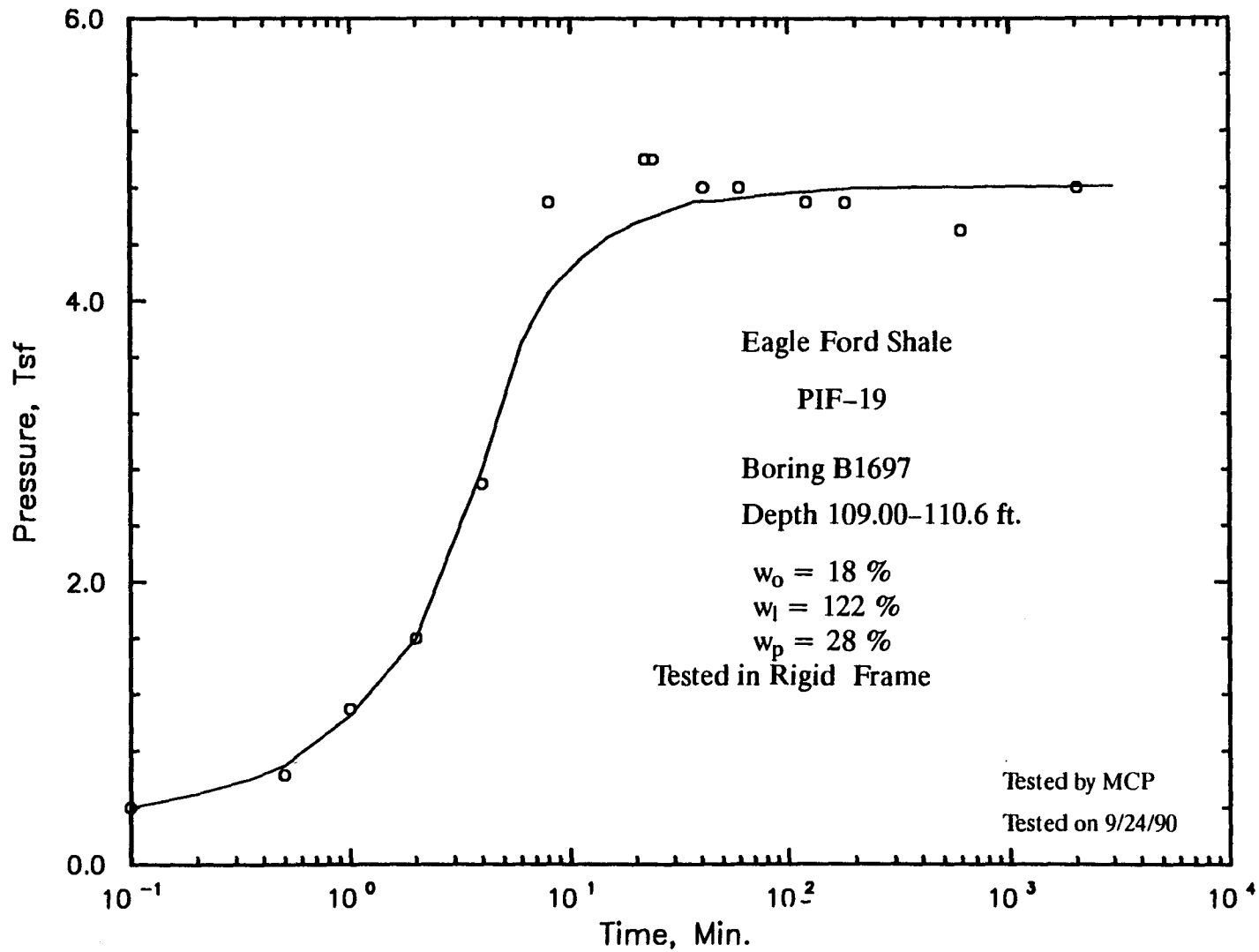


Fig. D3 Time-Rate of Swelling Pressure Development

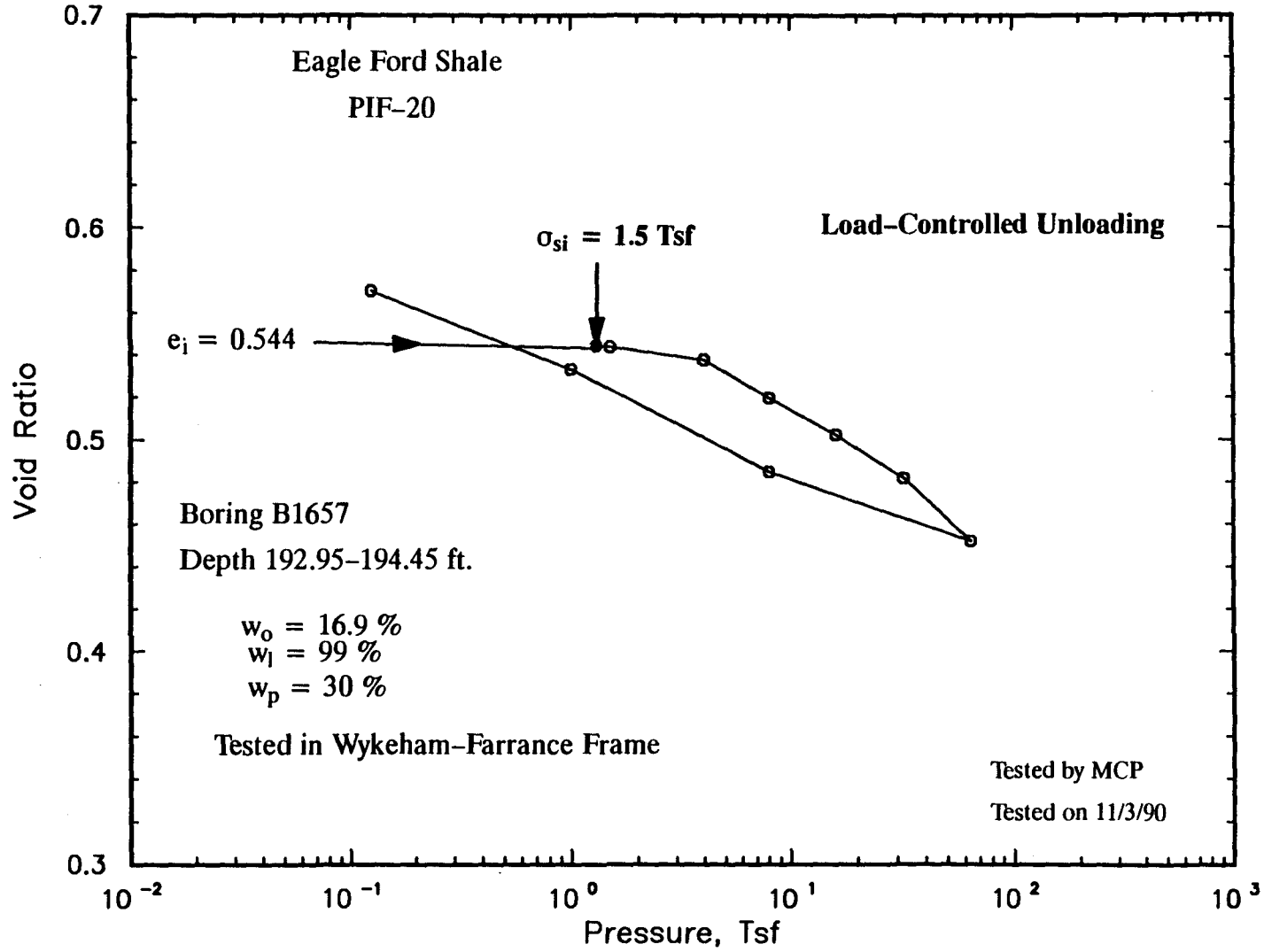


Fig. D4 Void Ratio - Log Pressure Relationship

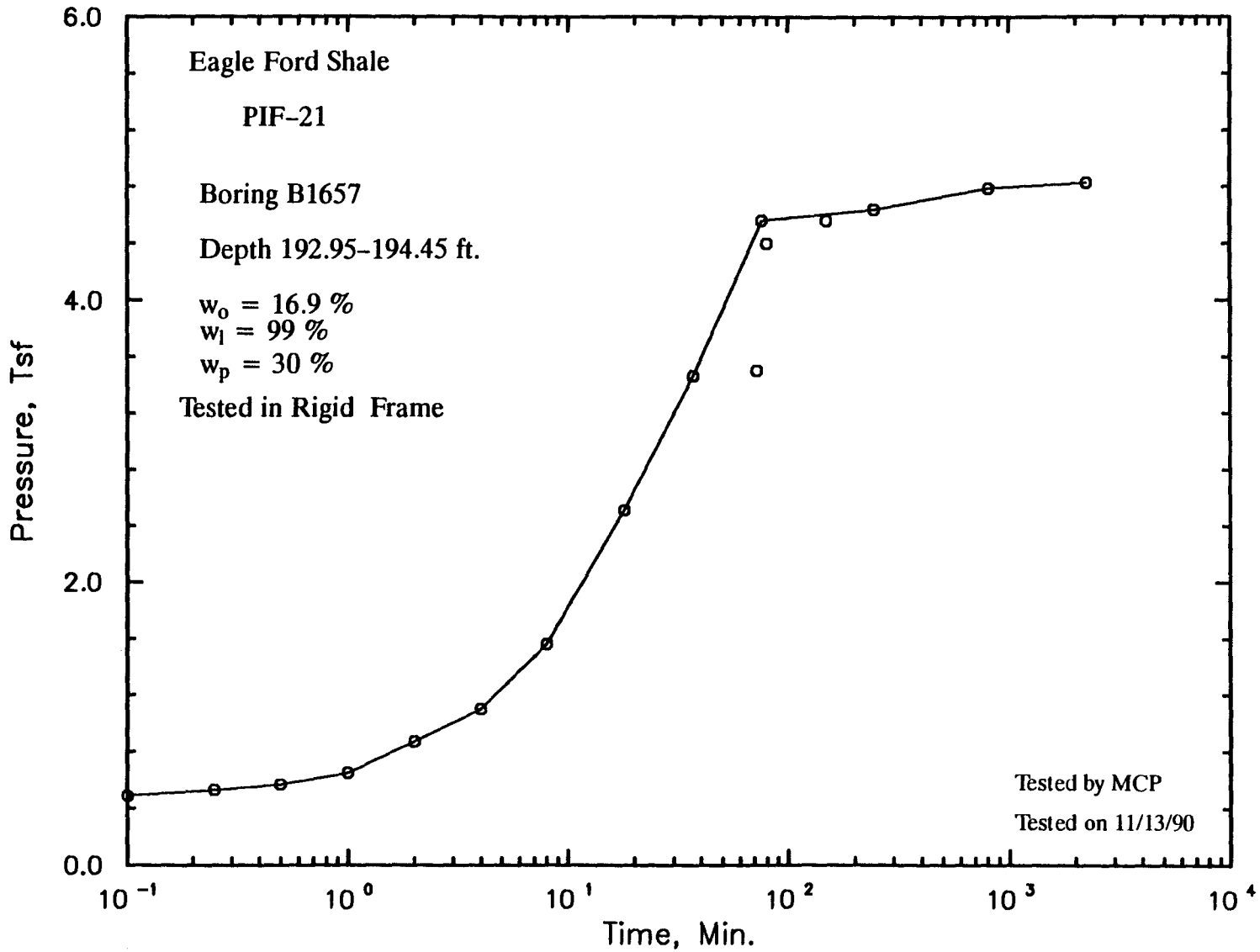


Fig. D5 Time-Rate of Swelling Pressure Development

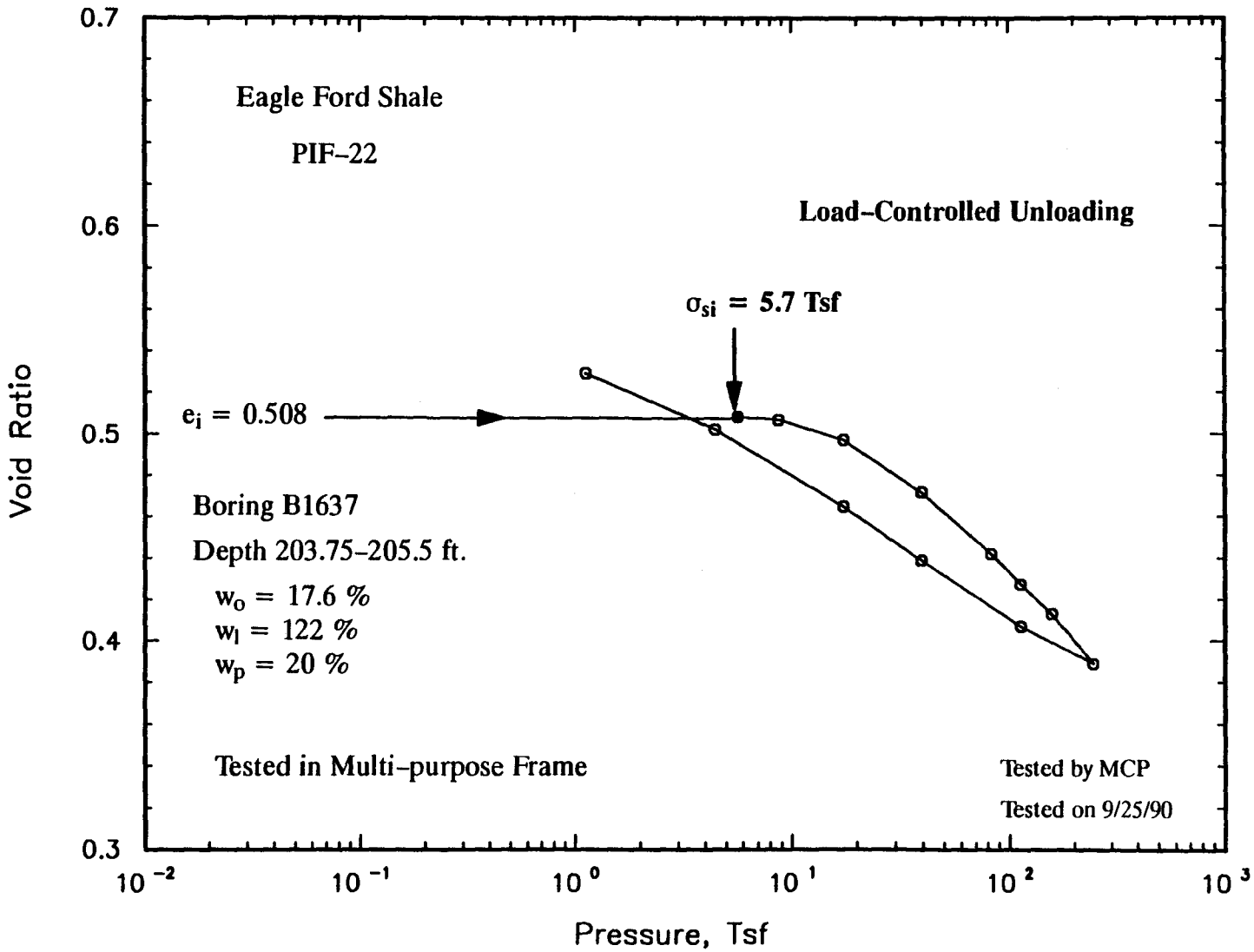


Fig. D6 Void Ratio – Log Pressure Relationship

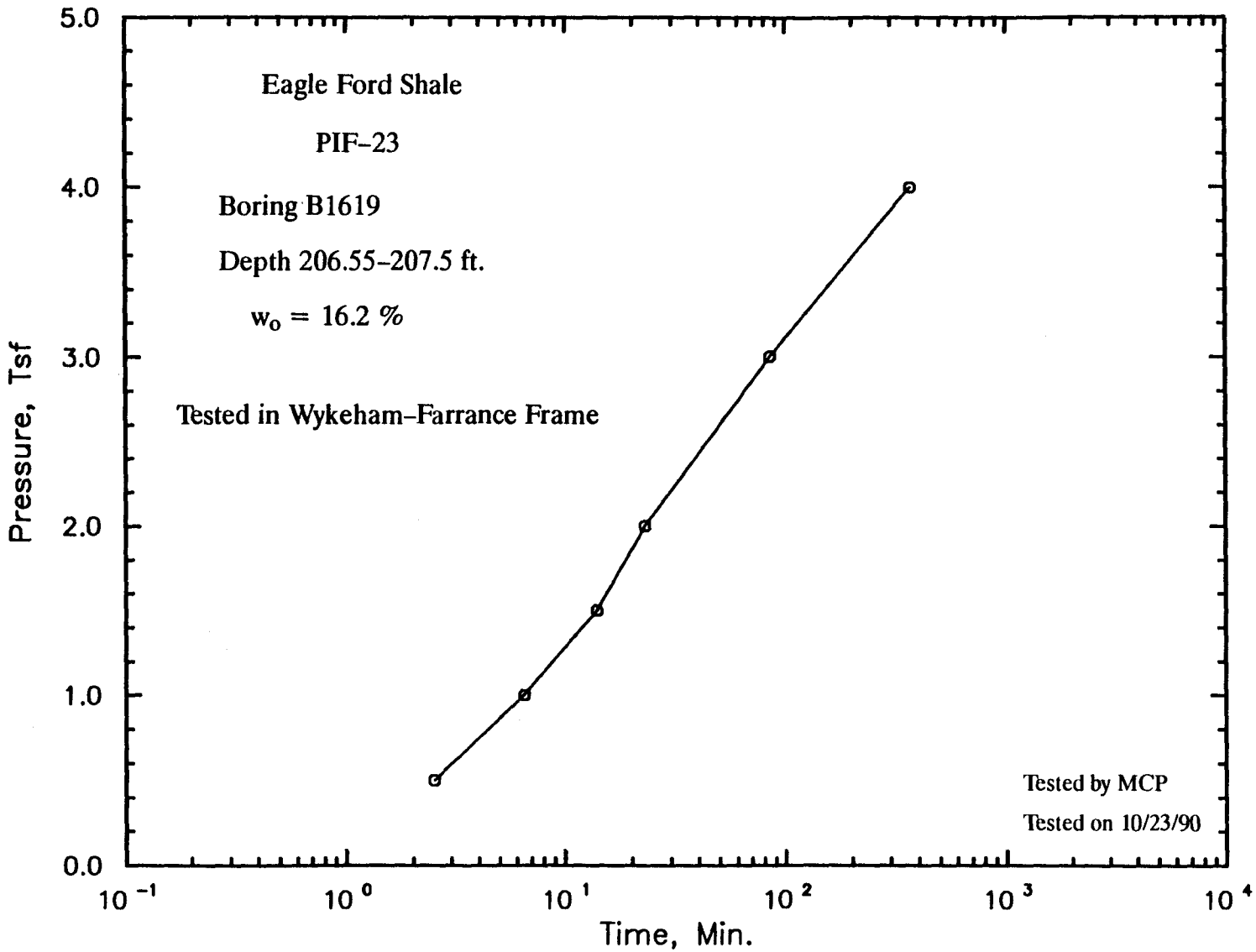


Fig. D7a Time-Rate of Swelling Pressure Development

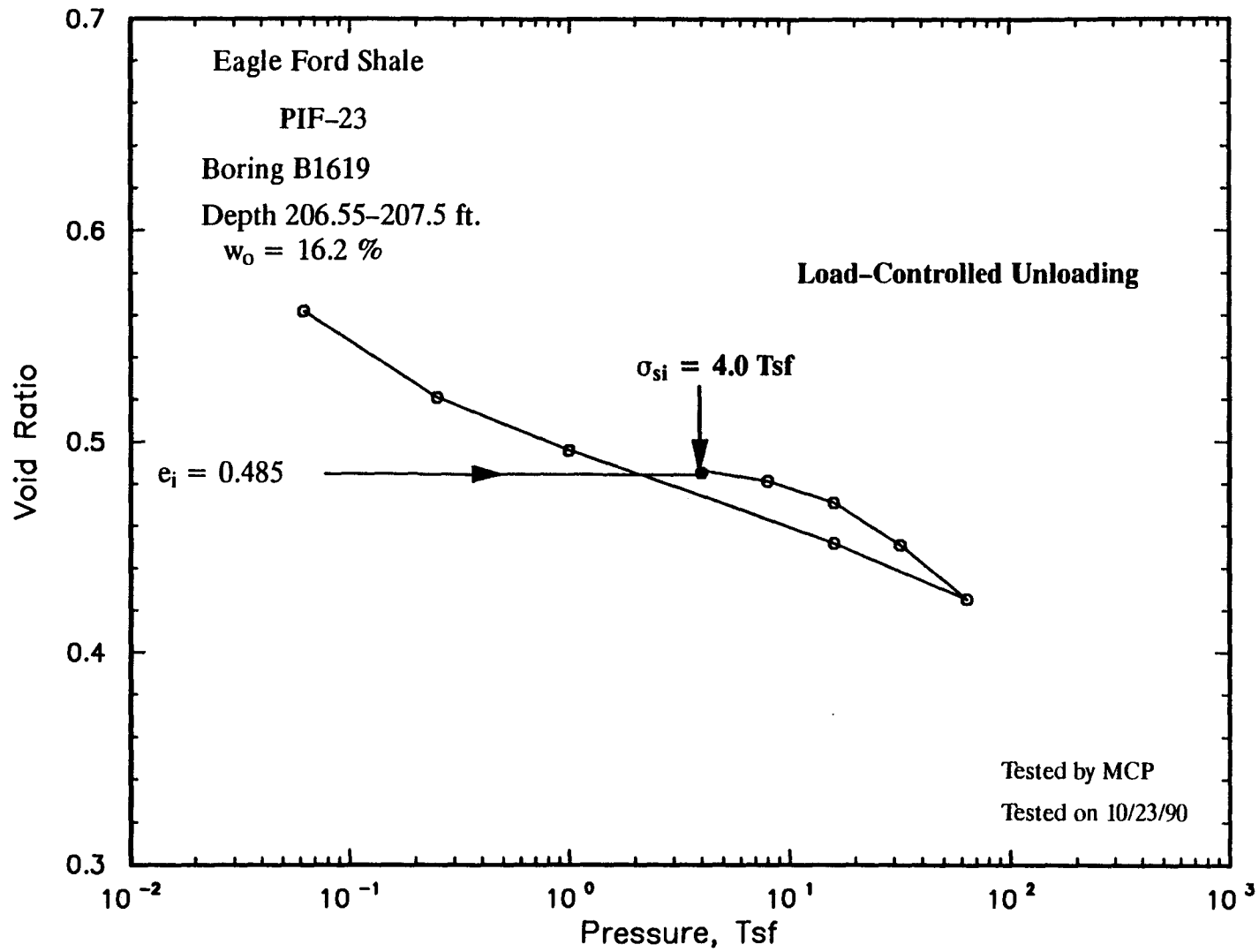


Fig. D7b Void Ratio - Log Pressure Relationship

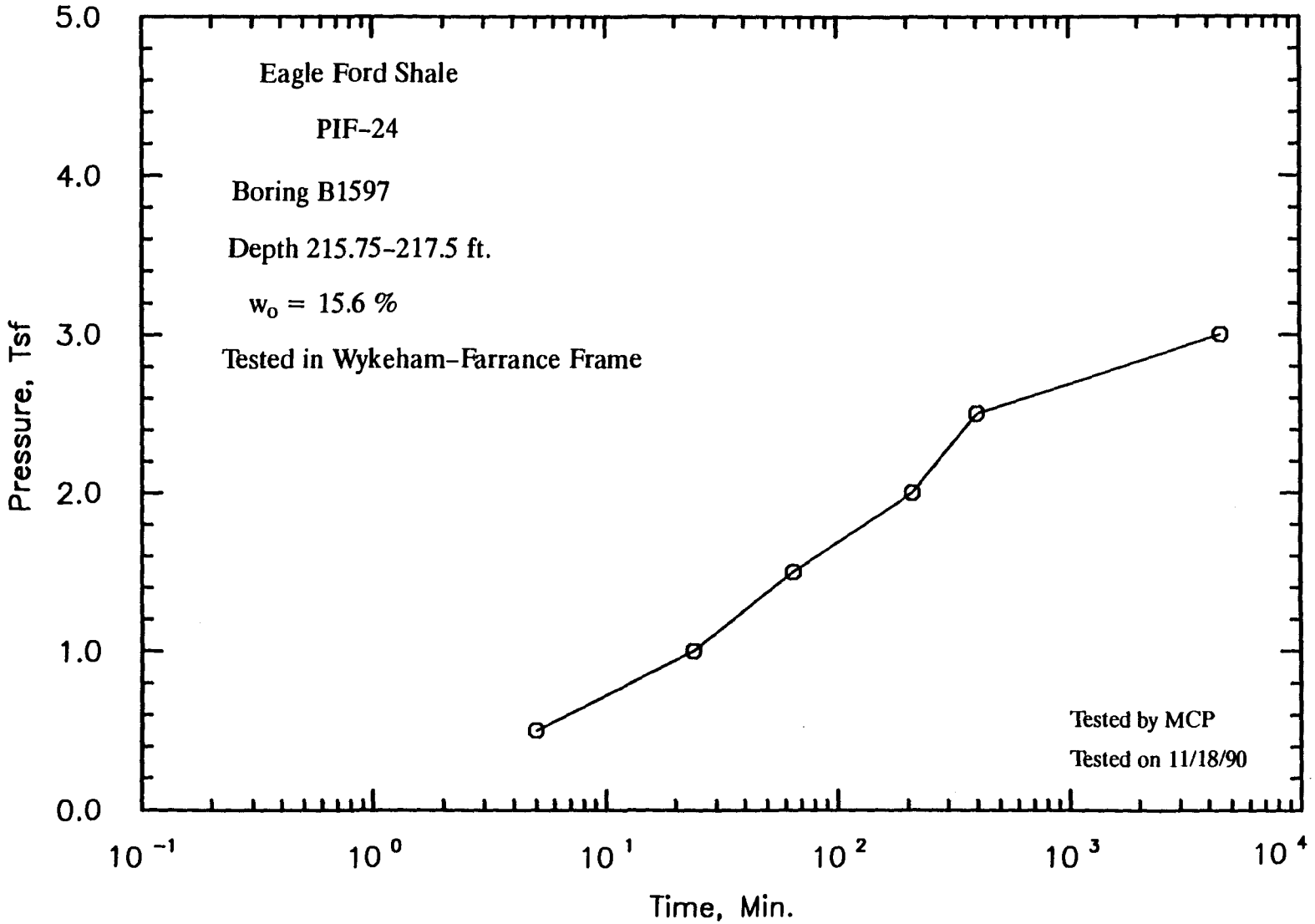


Fig. D8a Time-Rate of Swelling Pressure Development

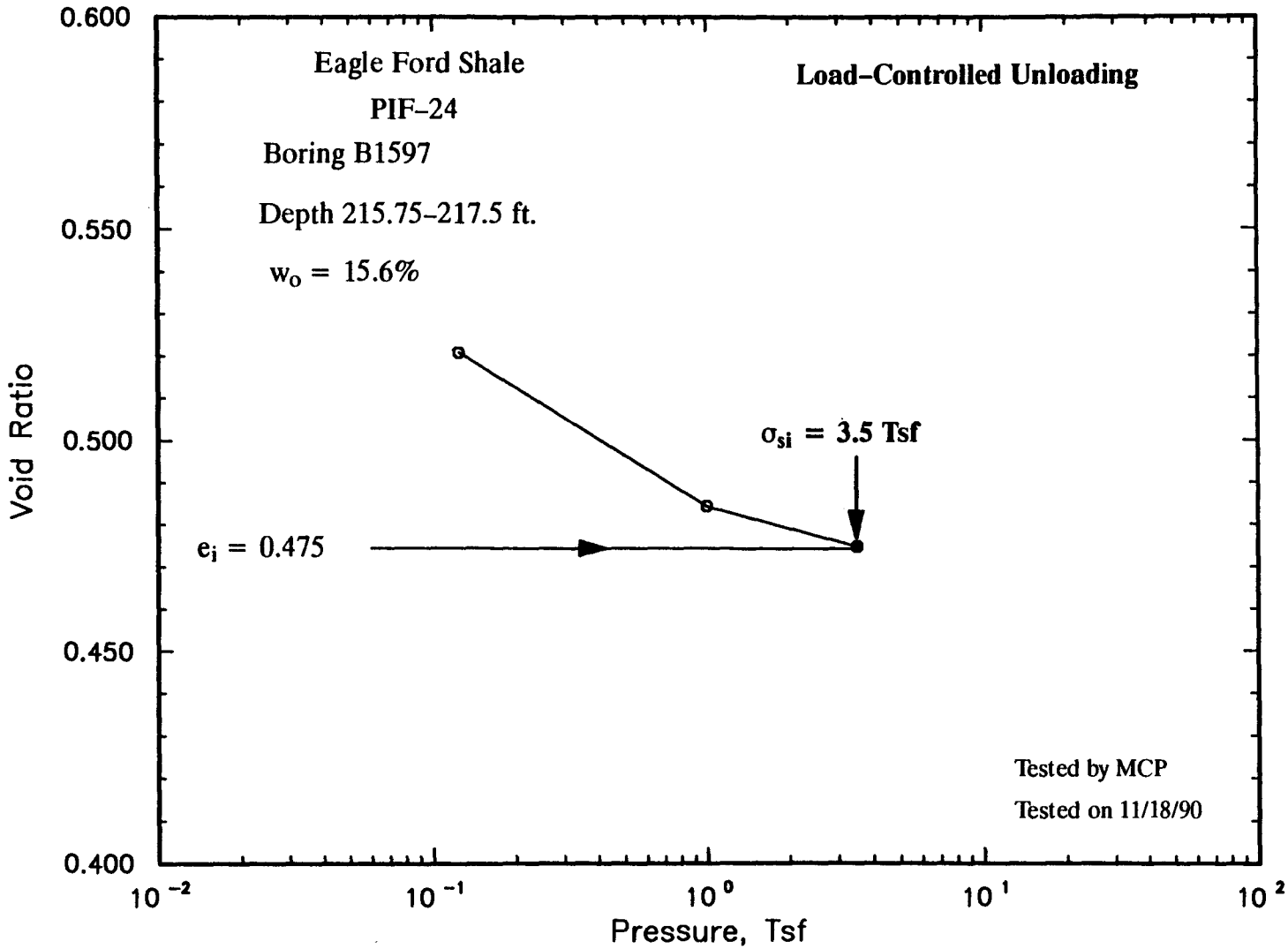


Fig. D8b Void Ratio - Log Pressure Relationship

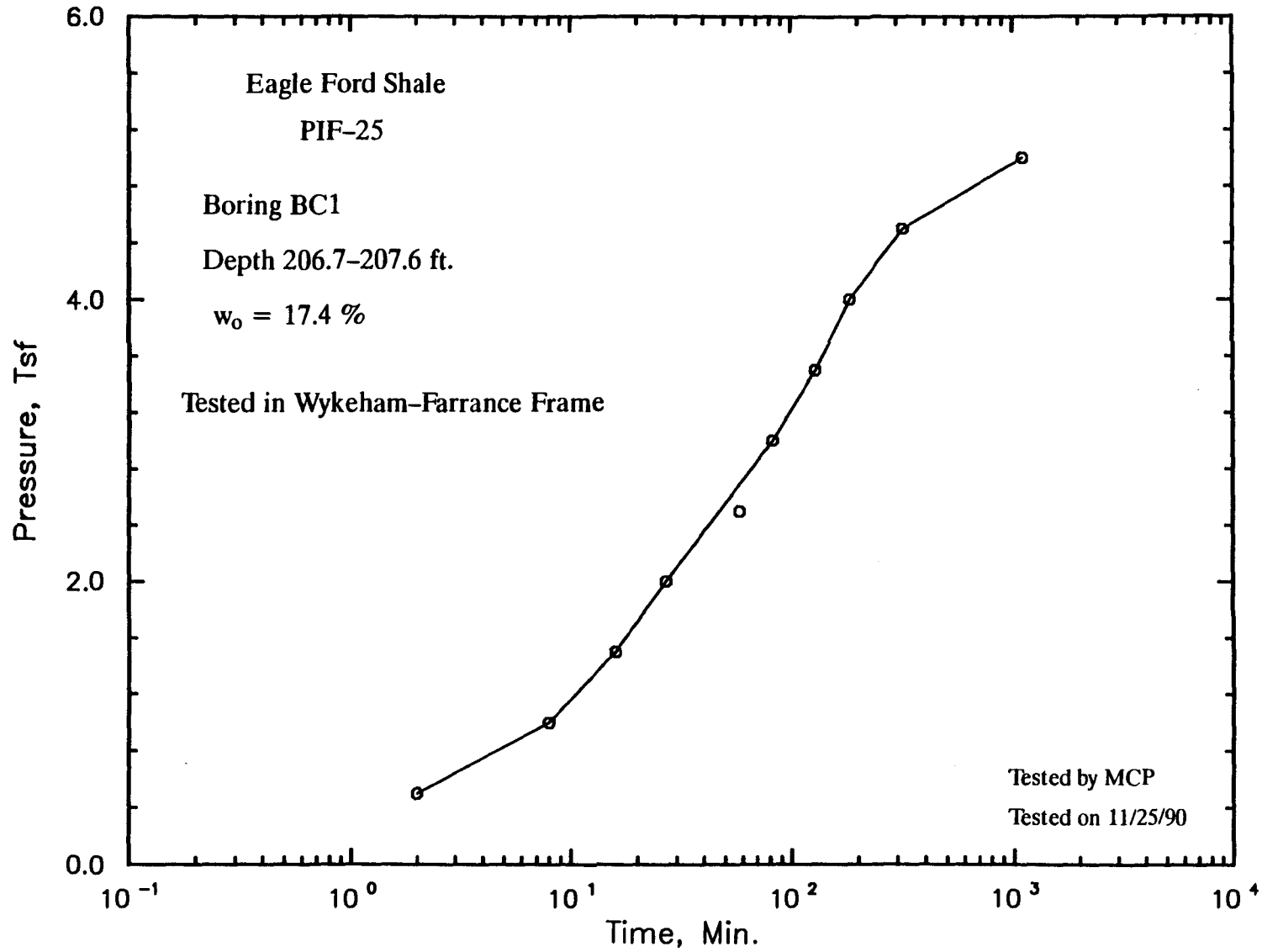


Fig. D9a Time-Rate of Swelling Pressure Development

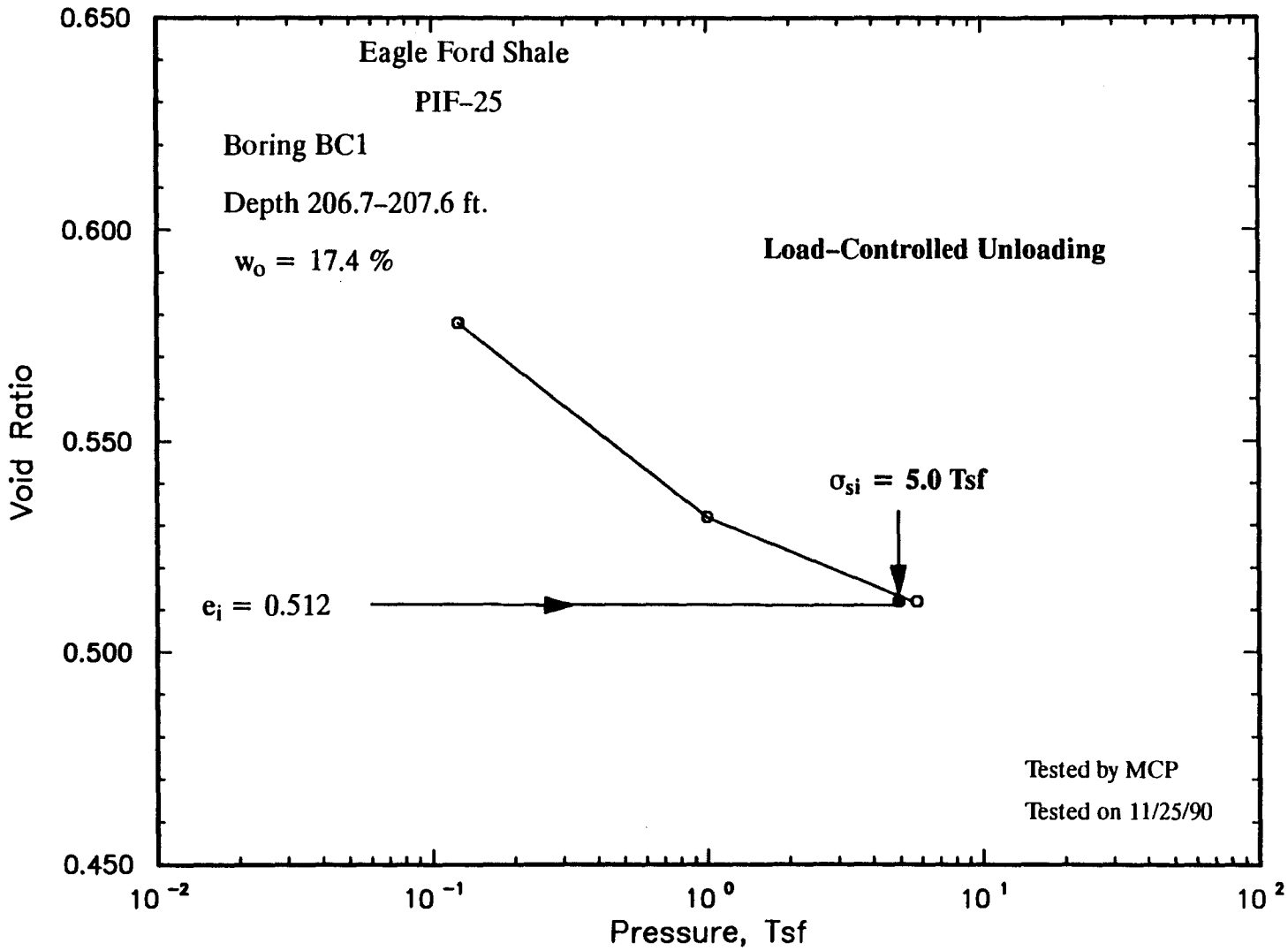


Fig. D9b Void Ratio - Log Pressure Relationship

APPENDIX EI

Figs. E1 - E8

Water Content-Log Computed Suction Pressure (and RH),
and Water Content-Log Time Relationships
for Deterioration Tests on Eagle Ford Shale

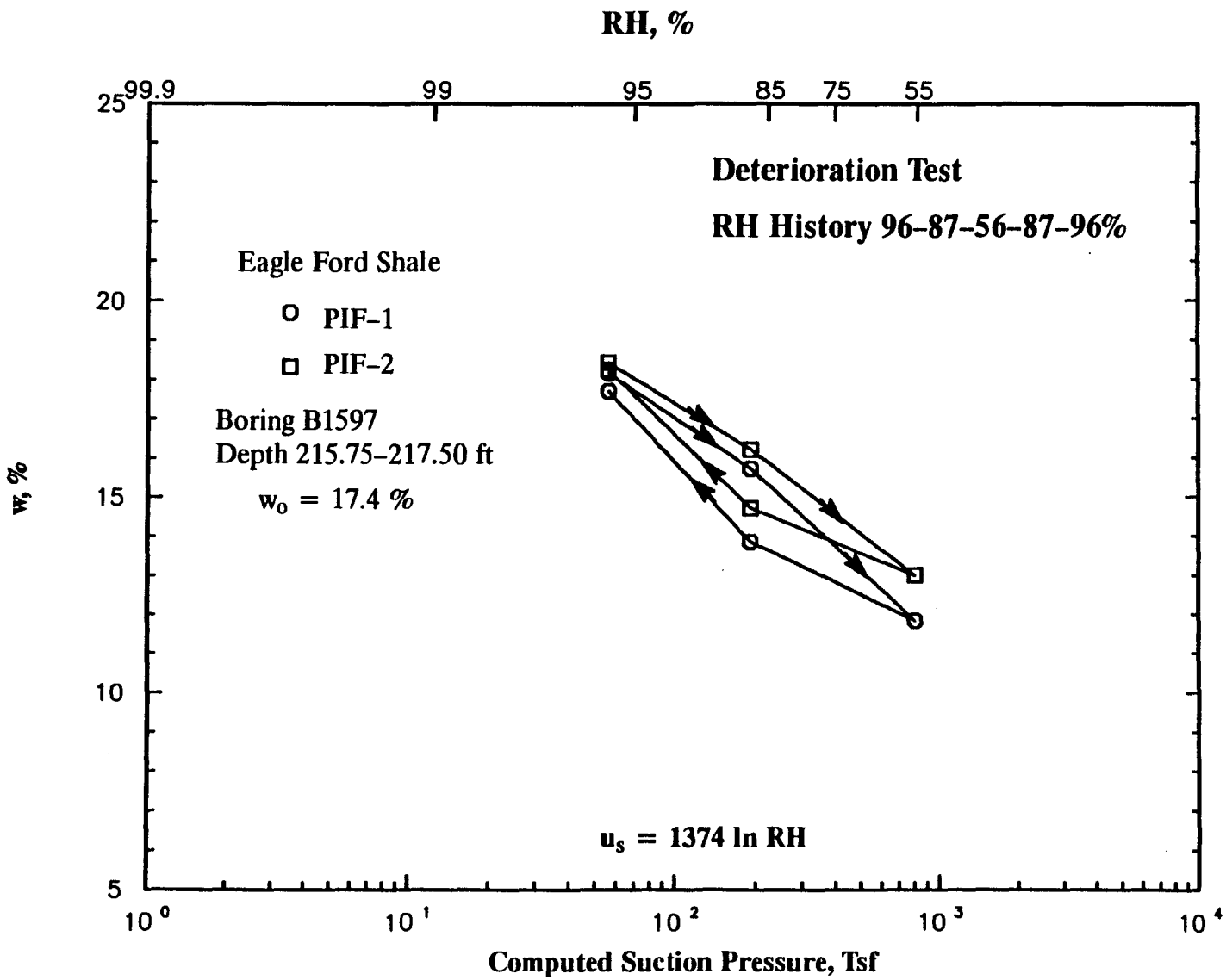


Fig. E1 Water Content – Relative Humidity Relationship

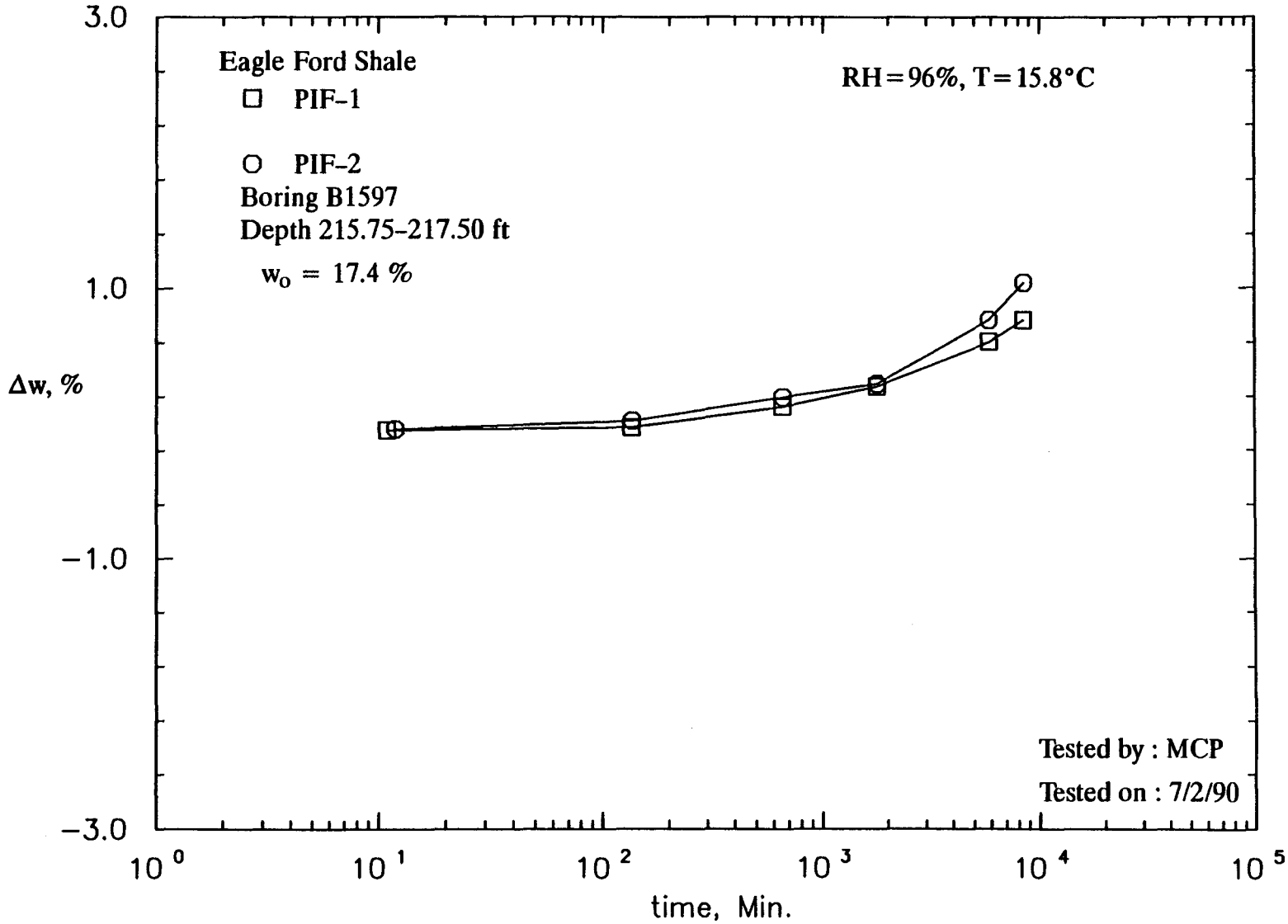


Fig. E1a Water Content Change – Log Time Relationship

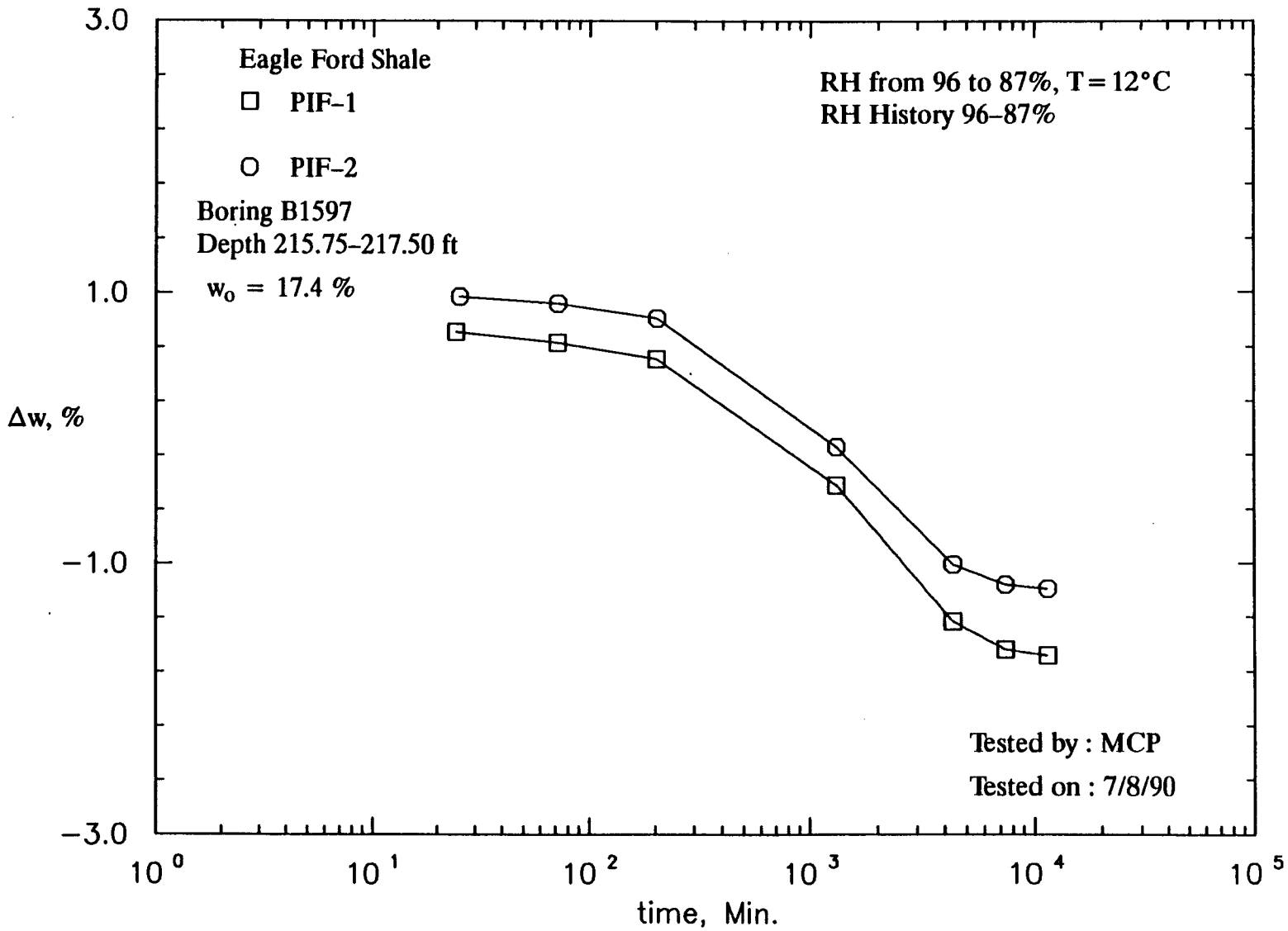


Fig. E1b Water Content Change – Log Time Relationship

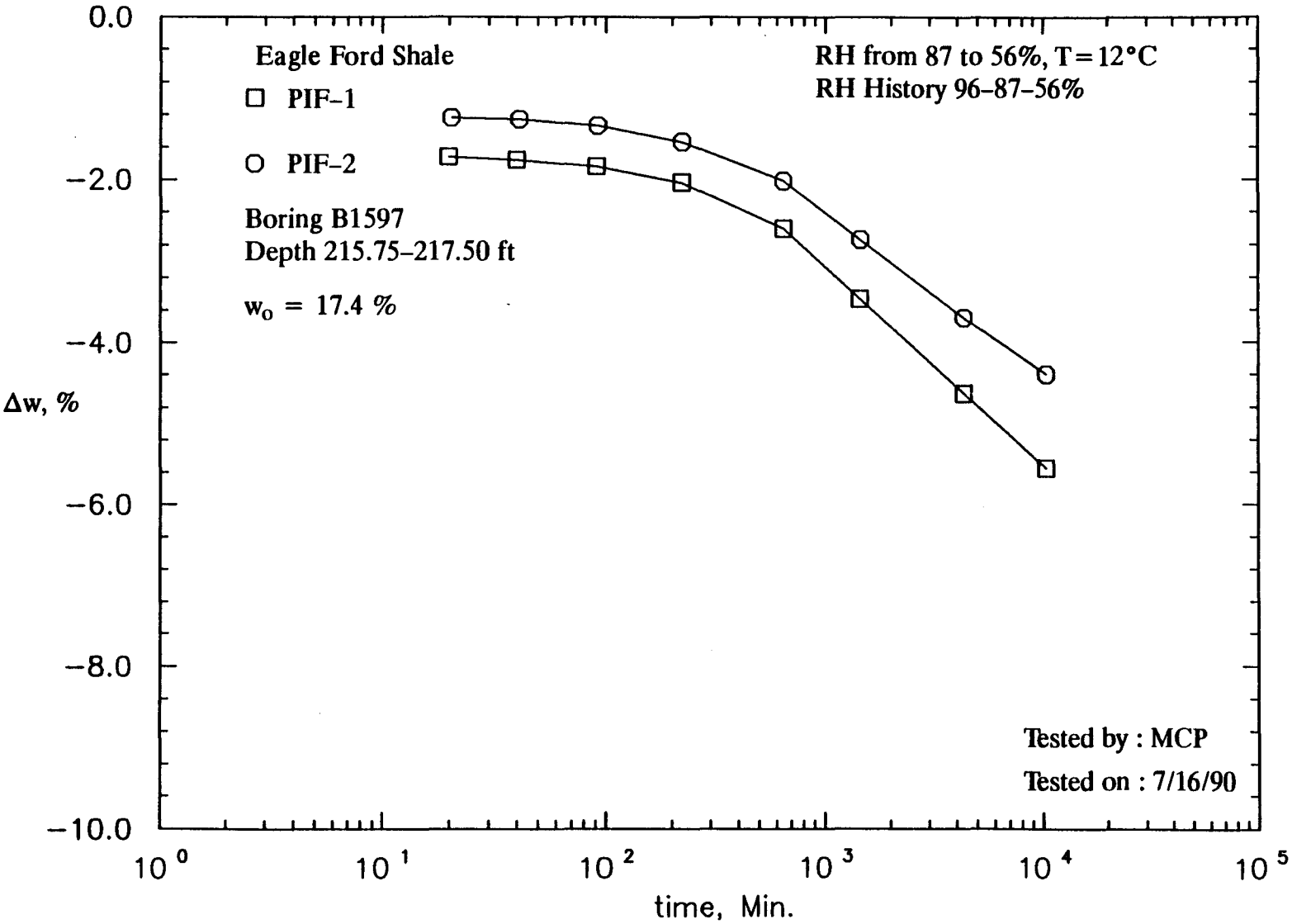


Fig. E1c Water Content Change – Log Time Relationship

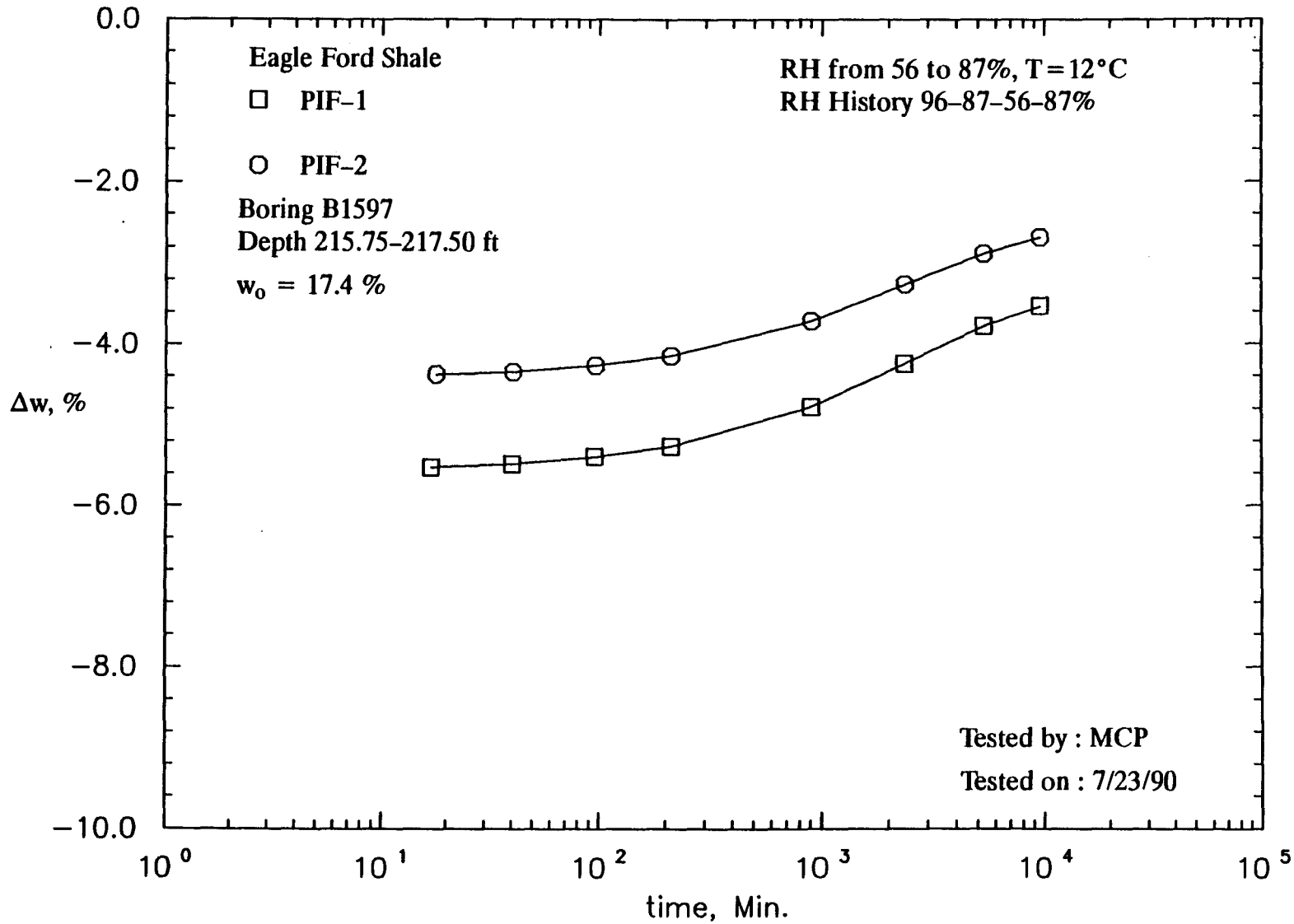


Fig. E1d Water Content Change – Log Time Relationship

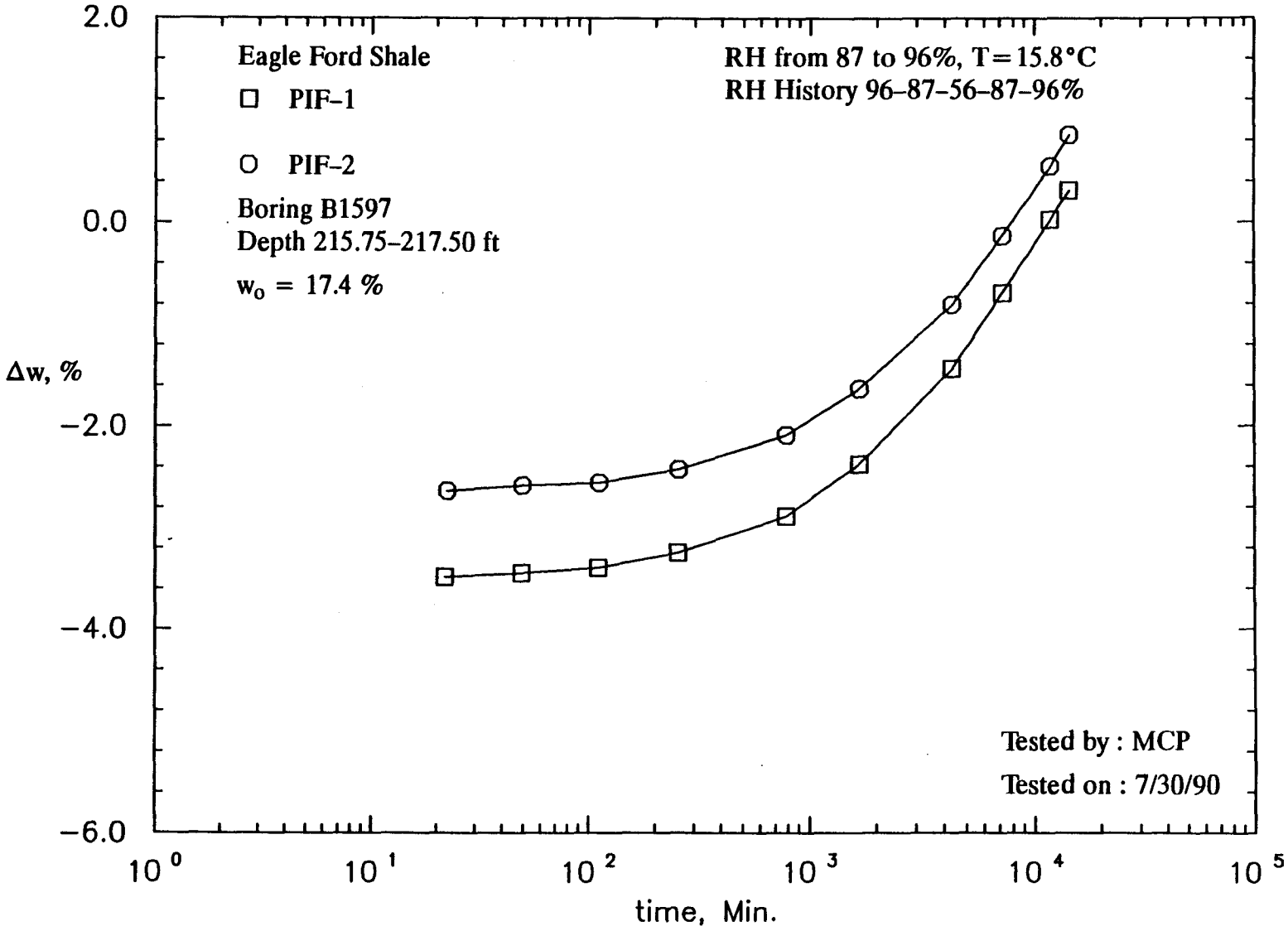


Fig. E1e Water Content Change – Log Time Relationship

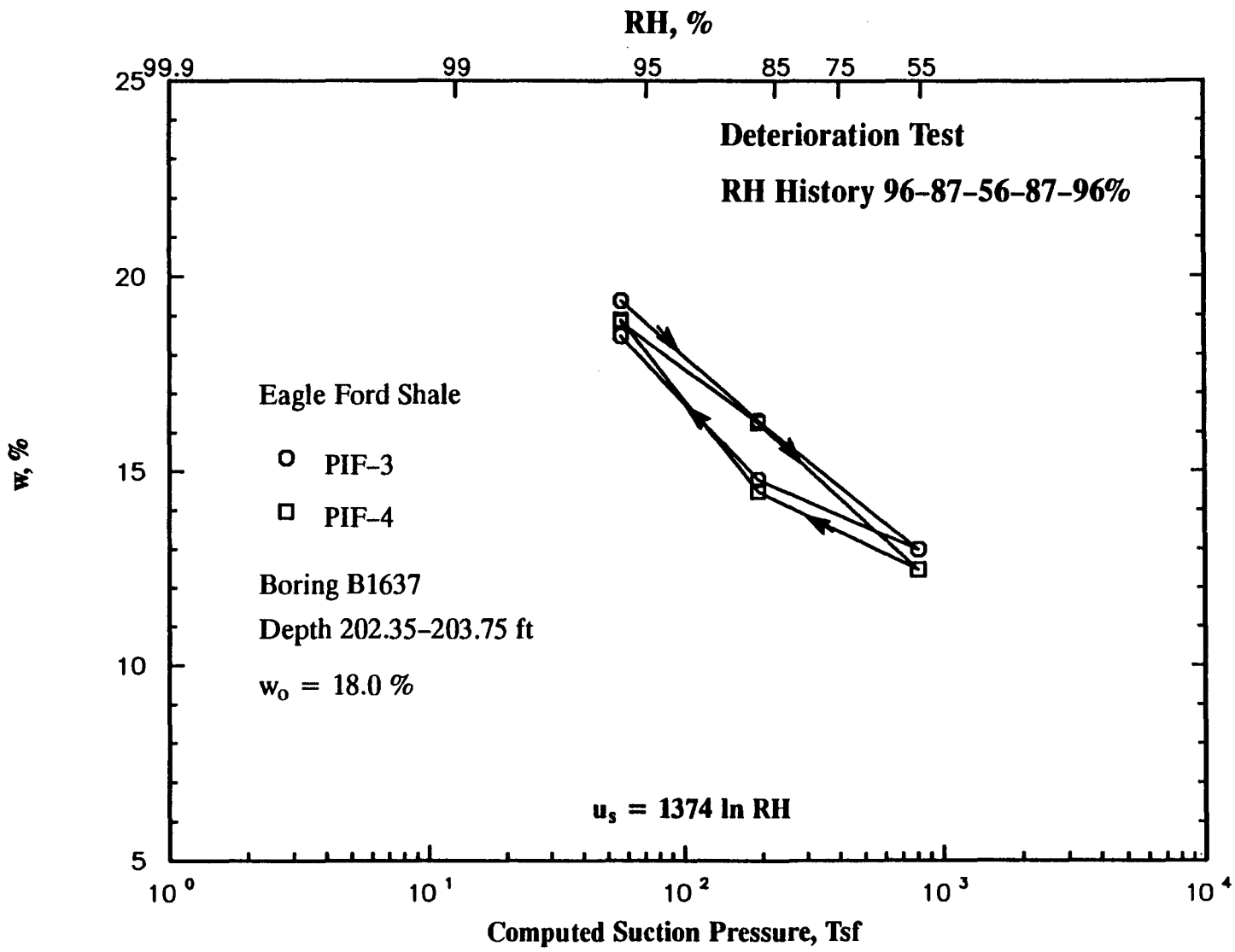


Fig. E2 Water Content – Relative Humidity Relationship

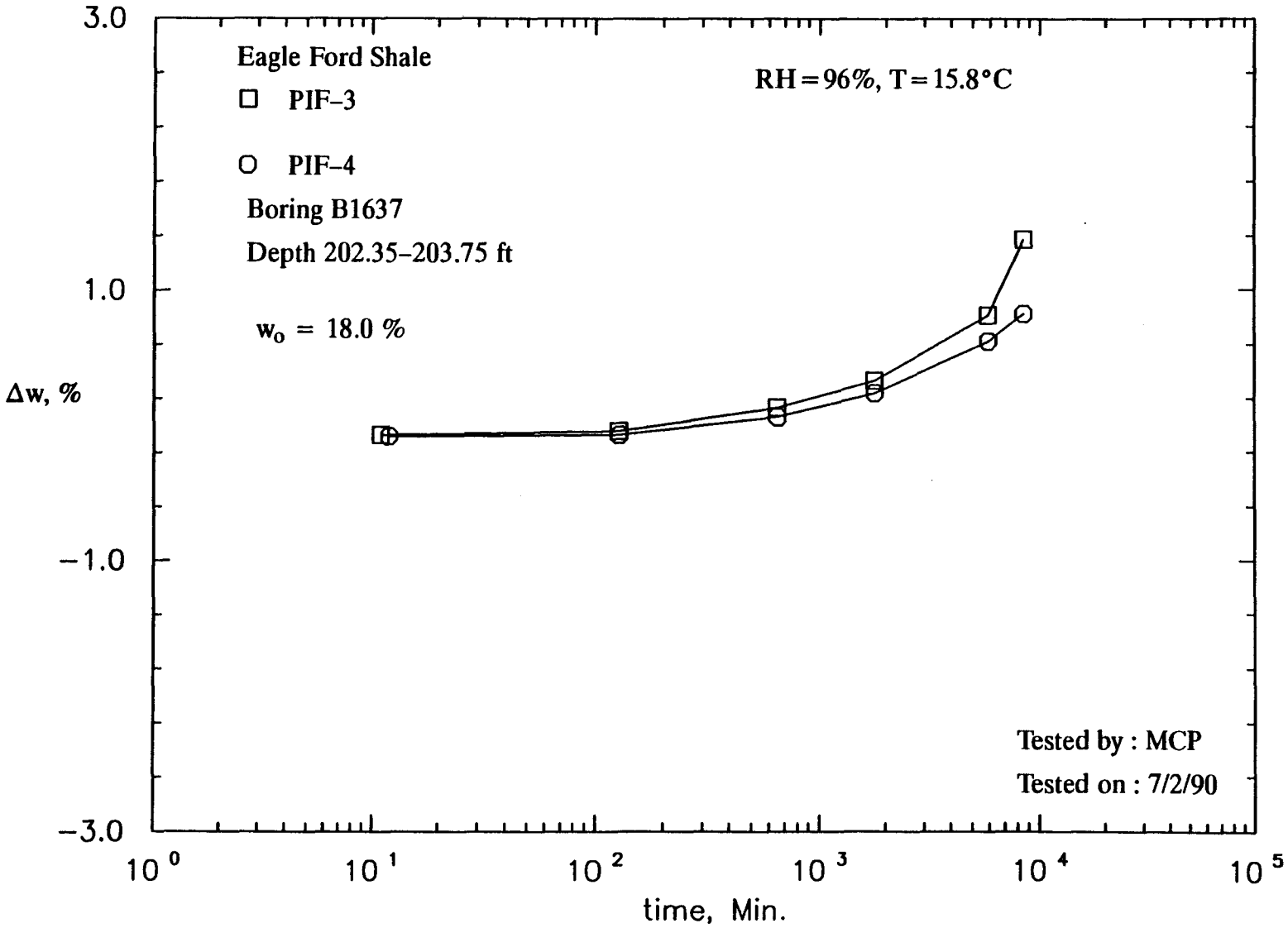


Fig. E2a Water Content Change – Log Time Relationship

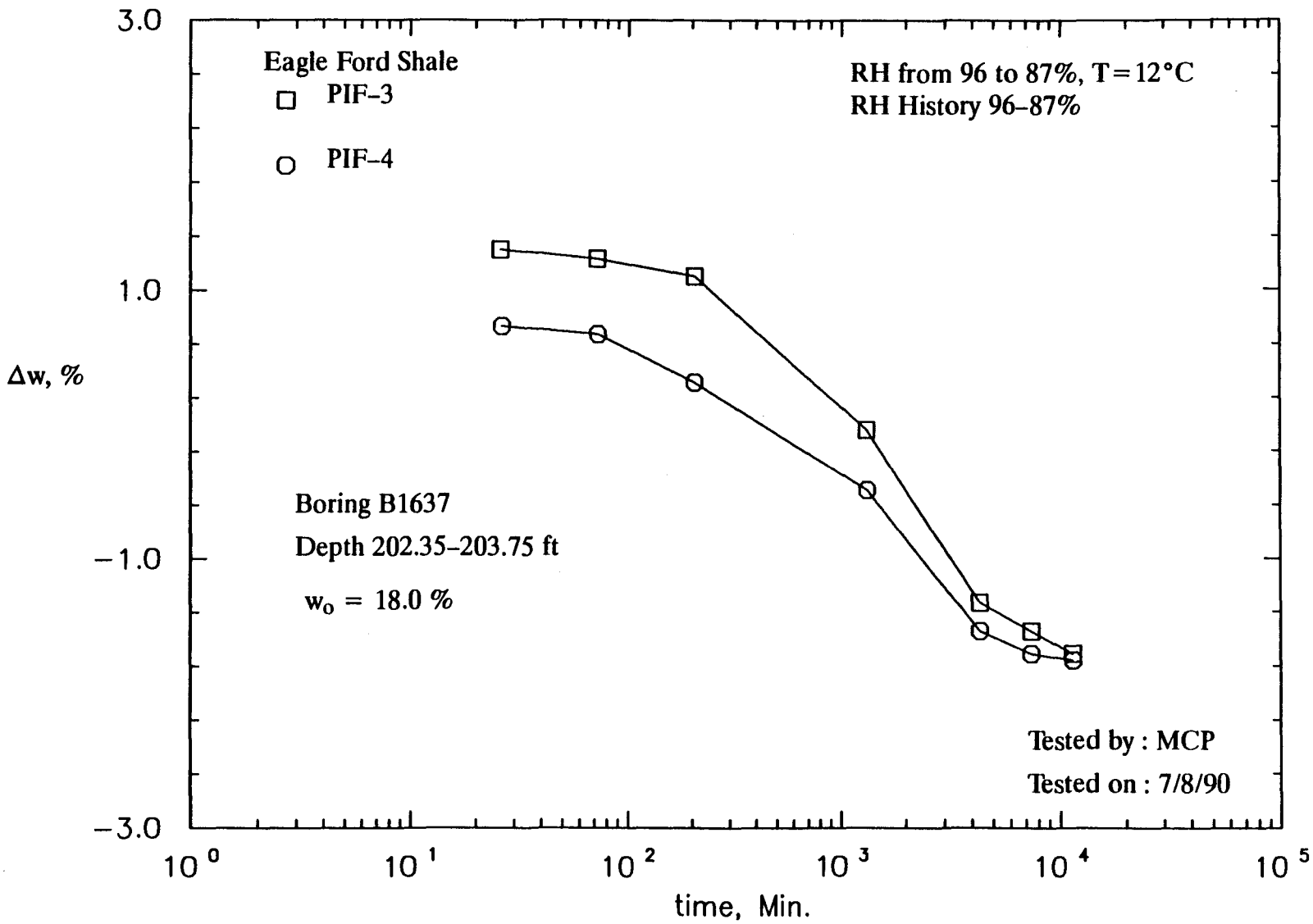


Fig. E2b Water Content Change – Log Time Relationship

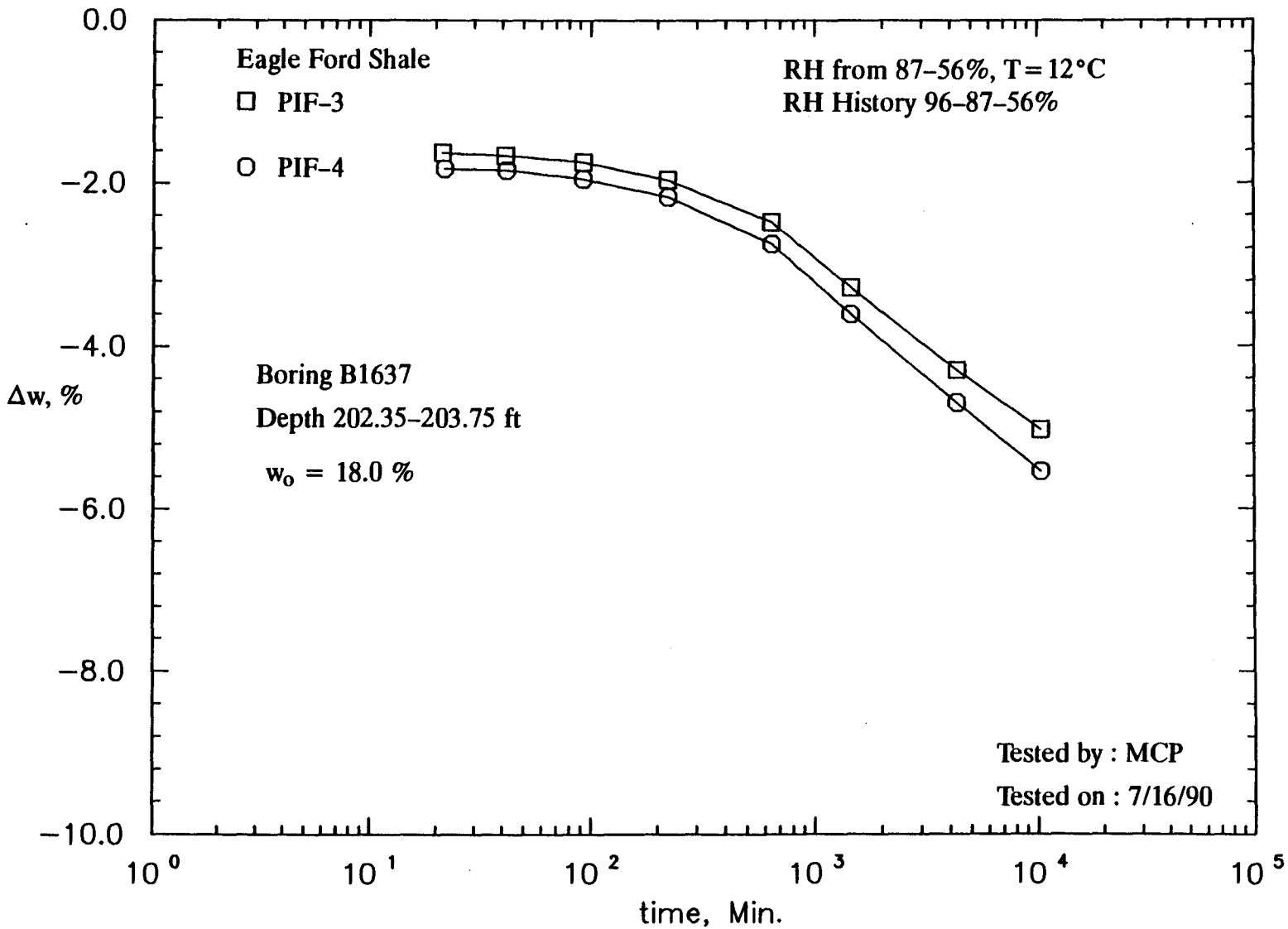


Fig. E2c Water Content Change – Log Time Relationship

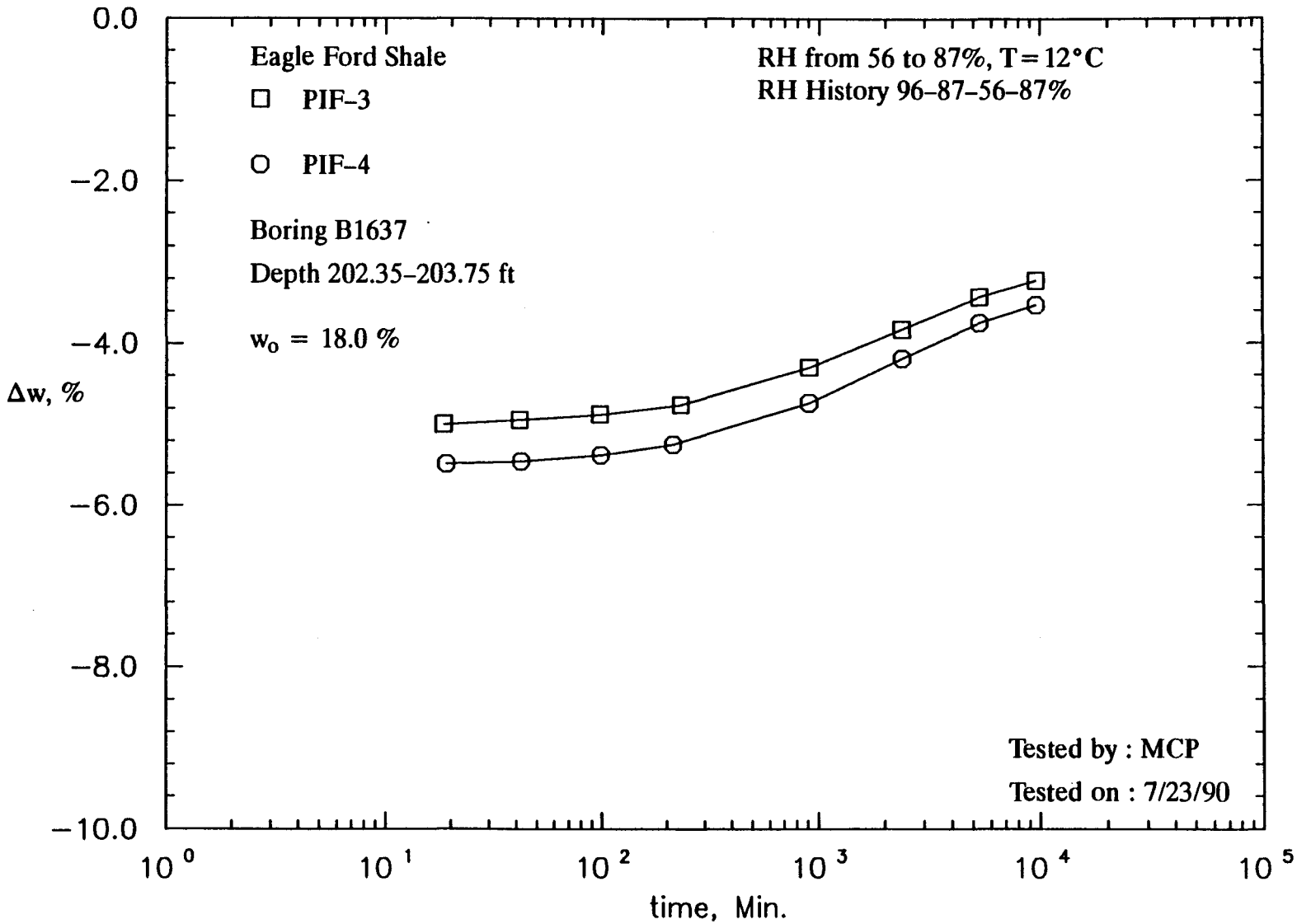


Fig. E2d Water Content Change – Log Time Relationship

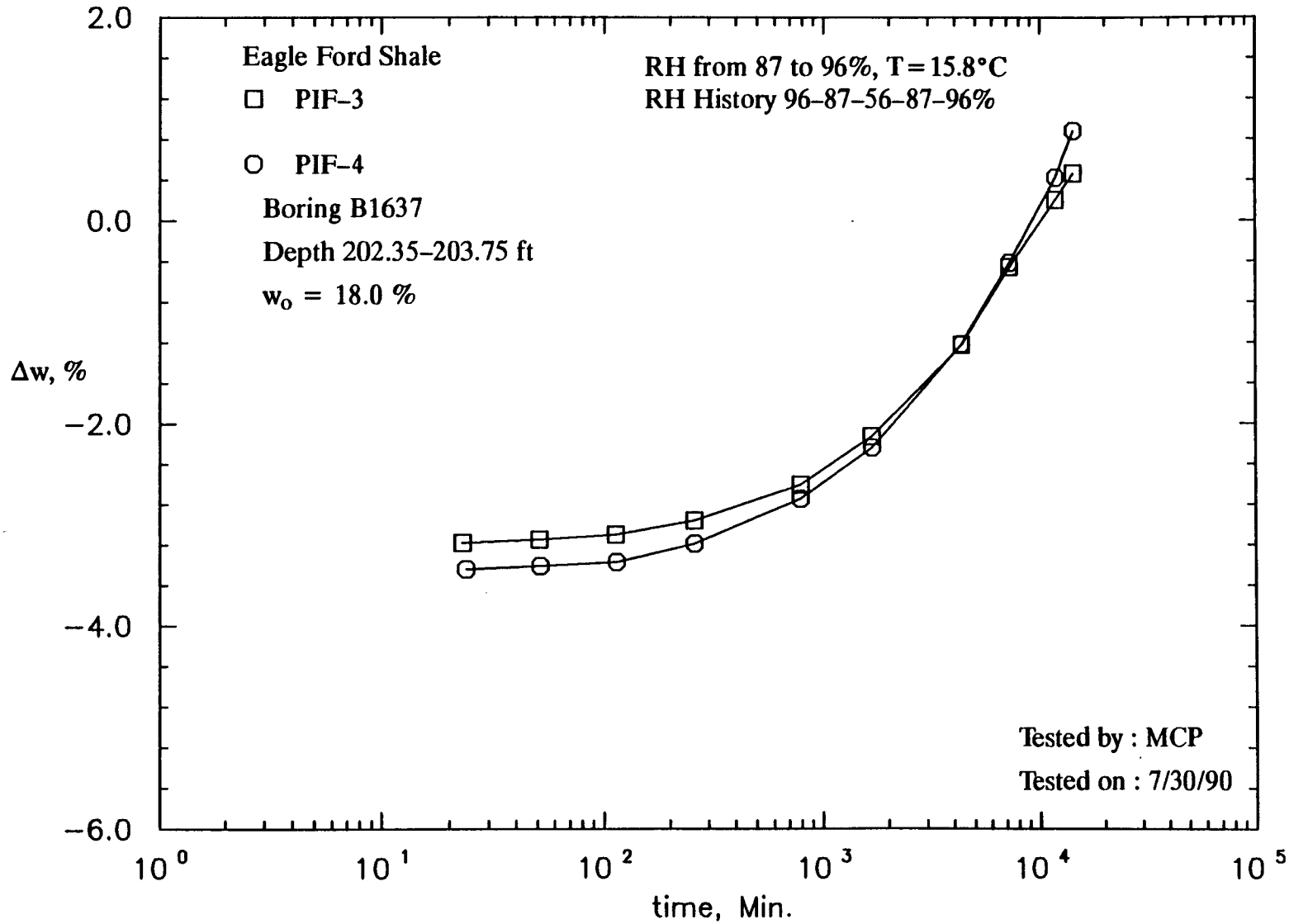


Fig. E2e Water Content Change – Log Time Relationship

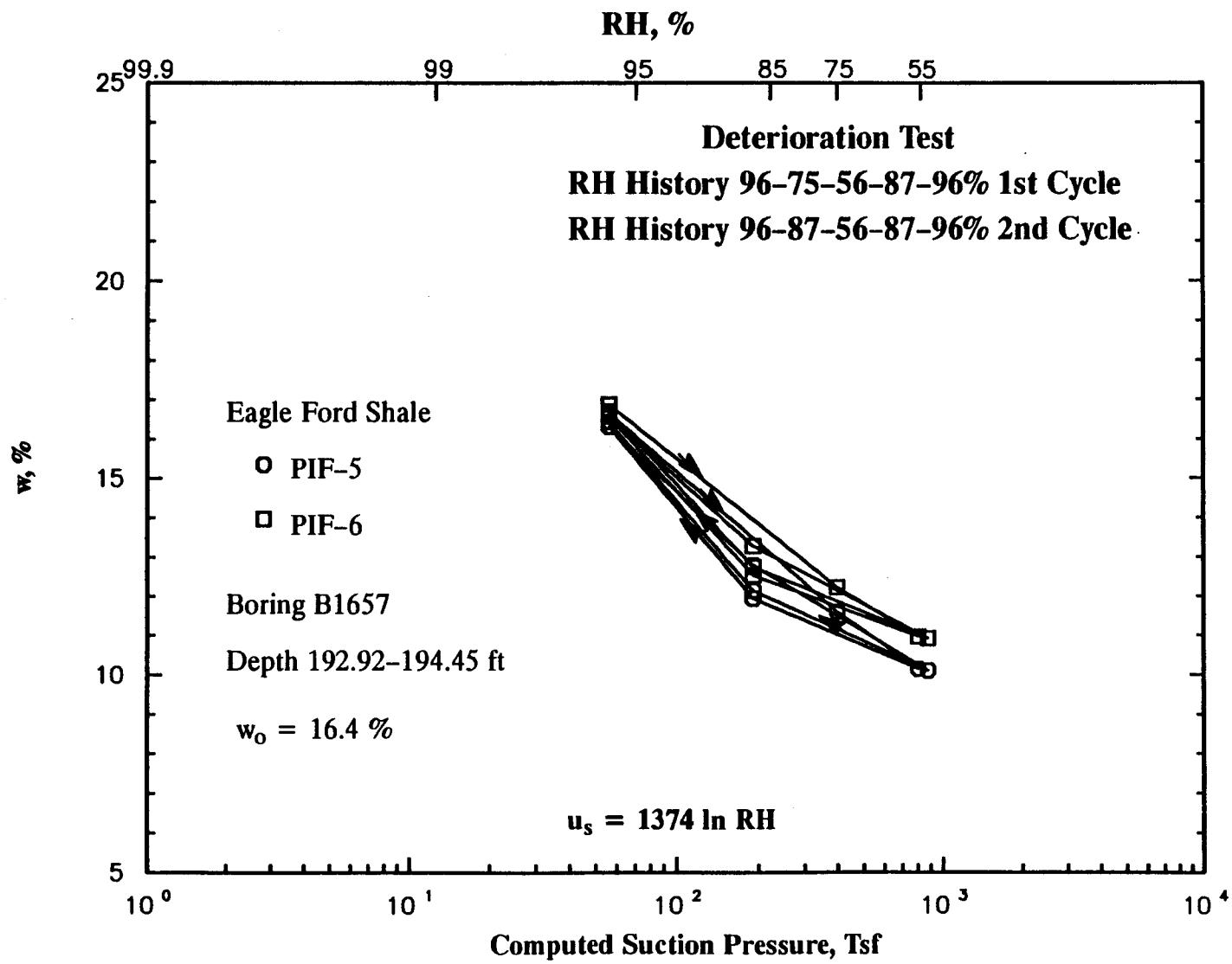


Fig. E3 Water Content – Relative Humidity Relationship

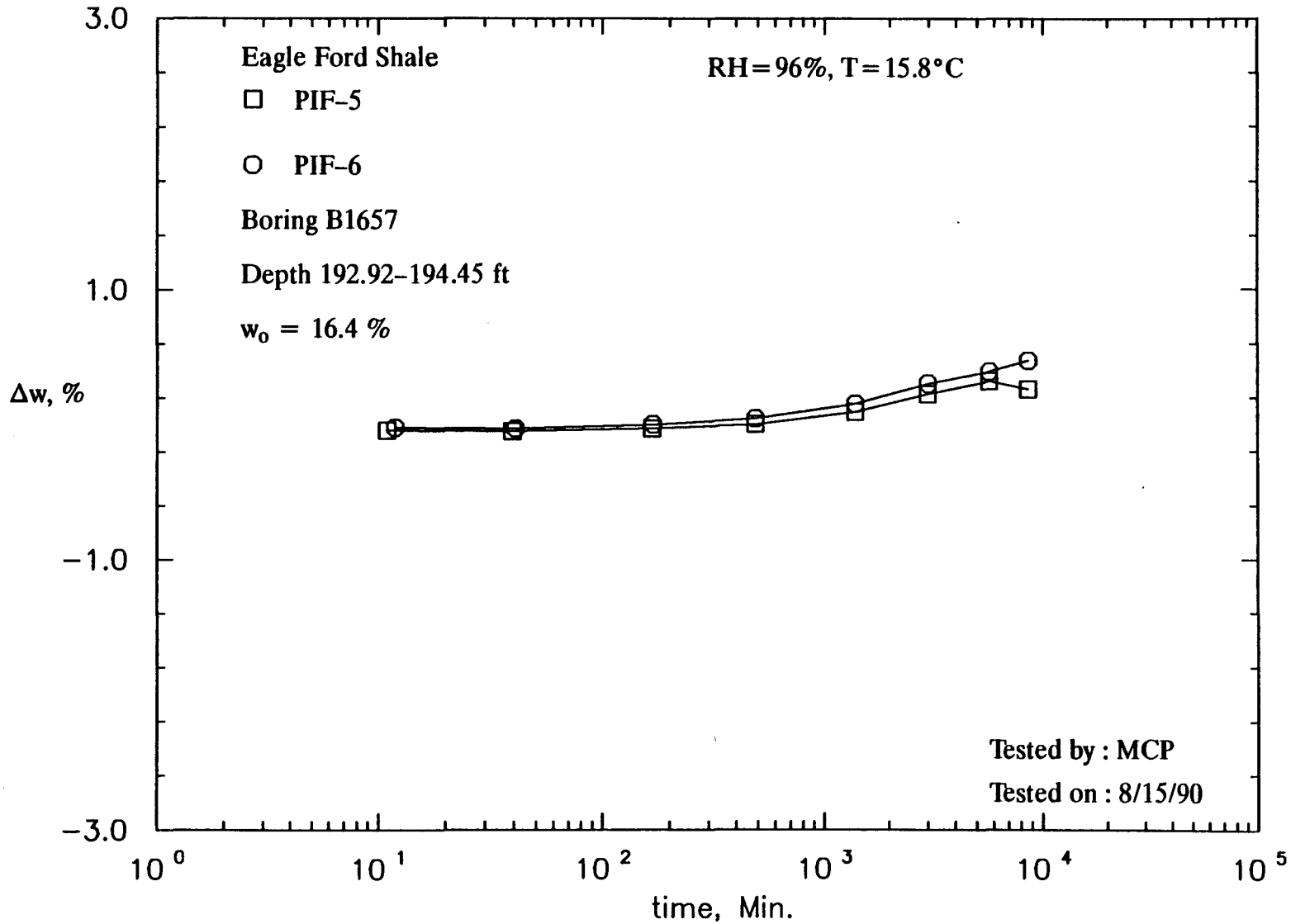


Fig. E3a Water Content Change – Log Time Relationship

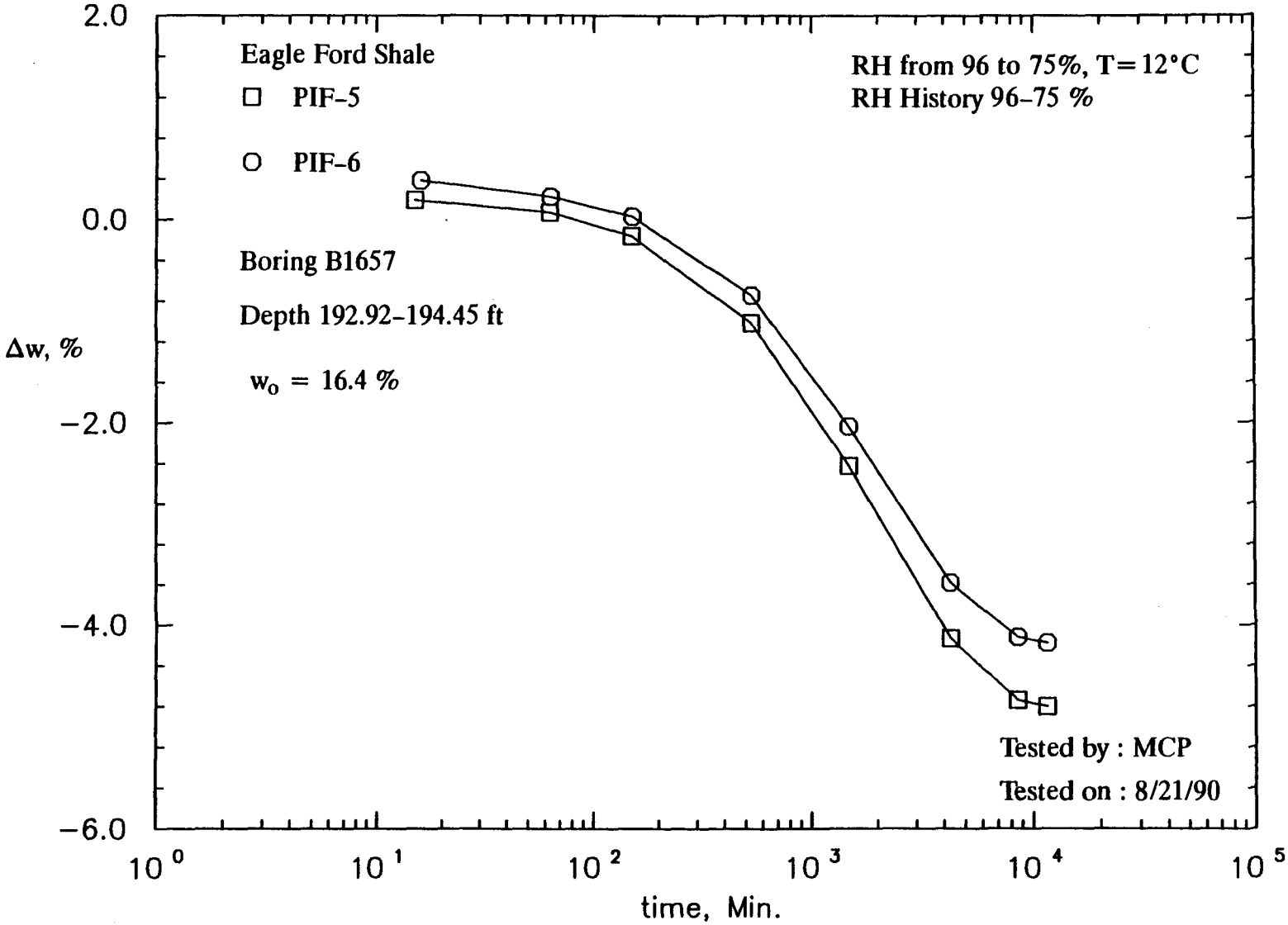


Fig. E3b Water Content Change – Log Time Relationship

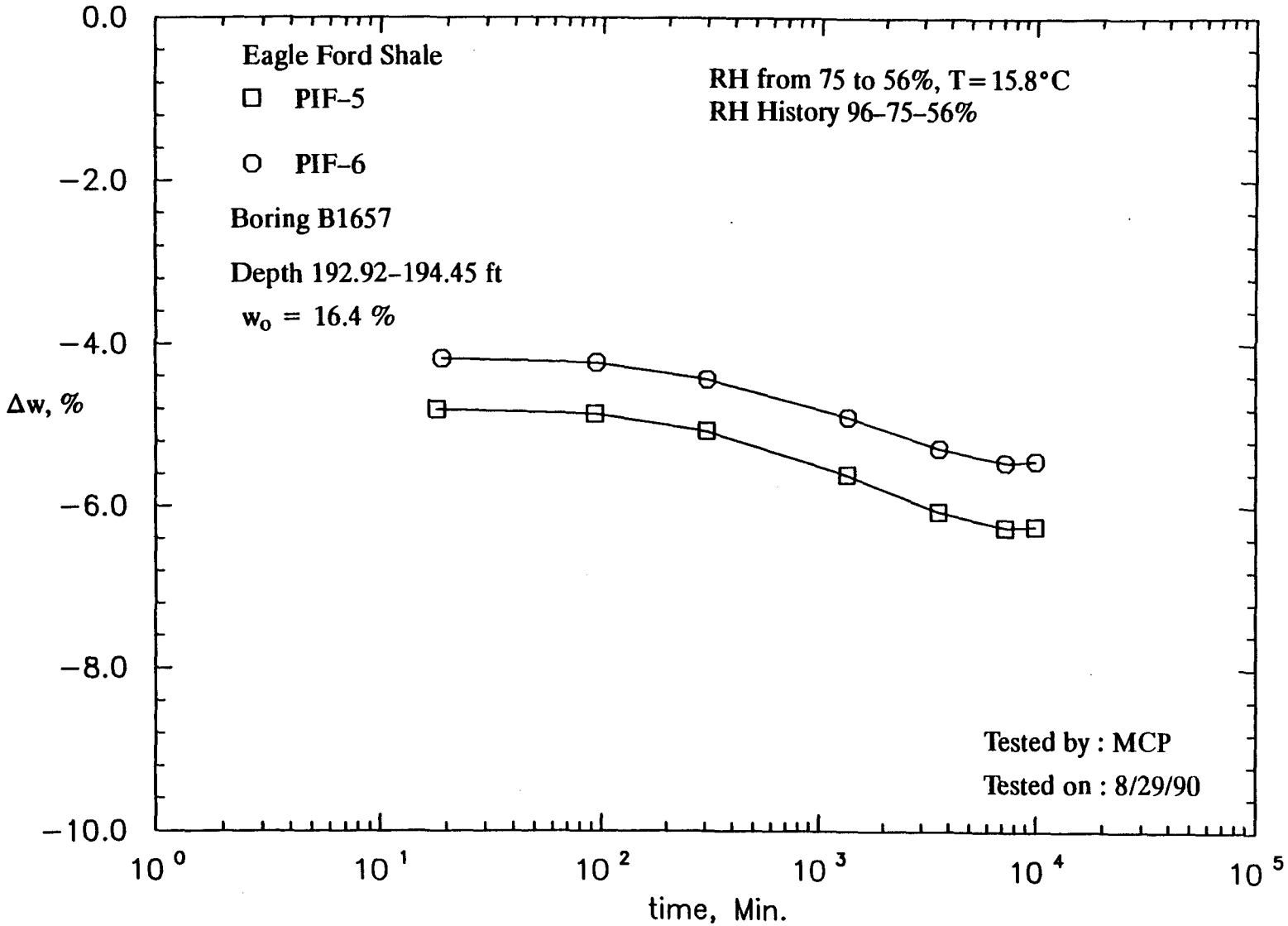


Fig. E3c Water Content Change - Log Time Relationship

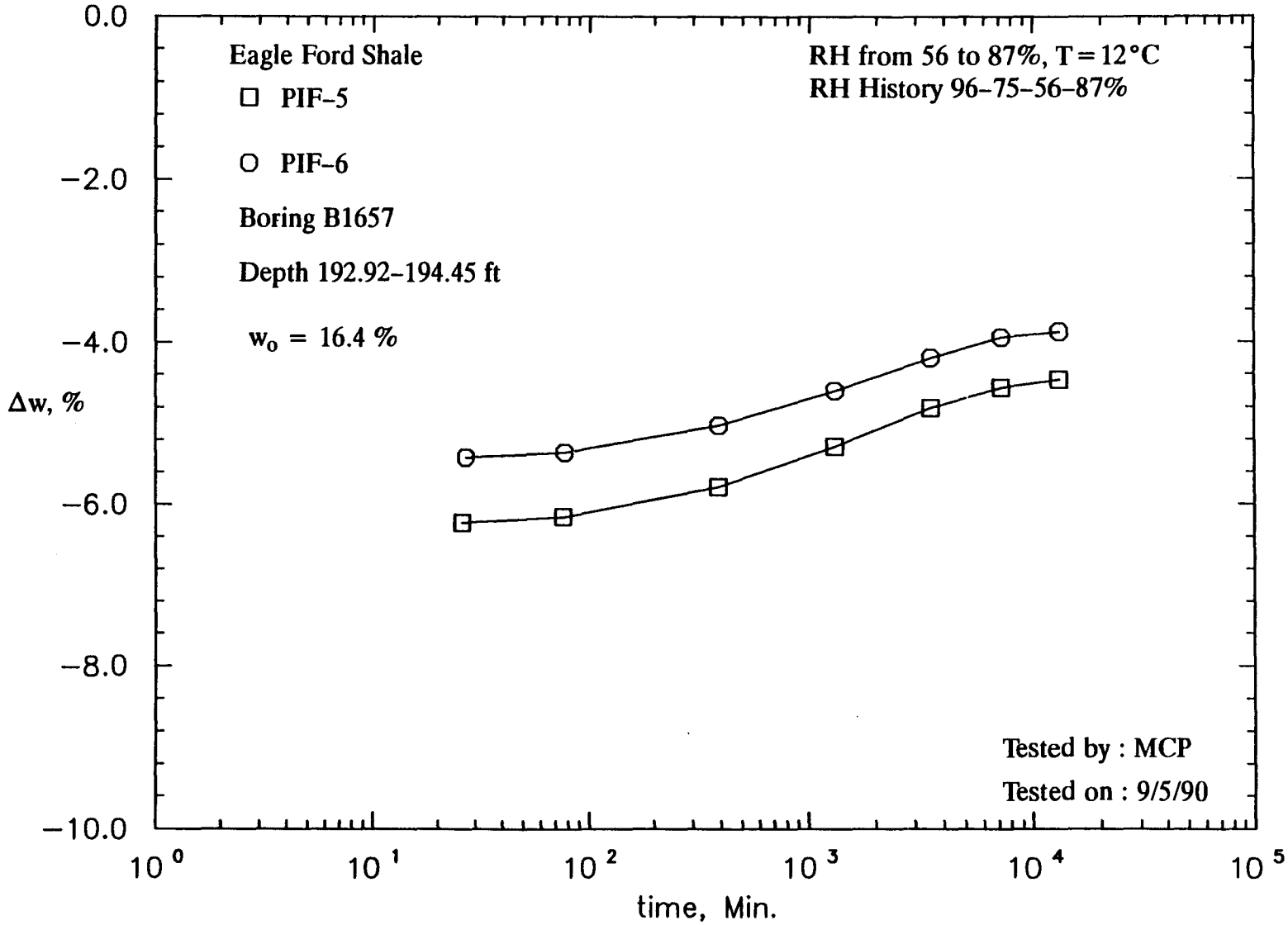


Fig. E3d Water Content Change – Log Time Relationship

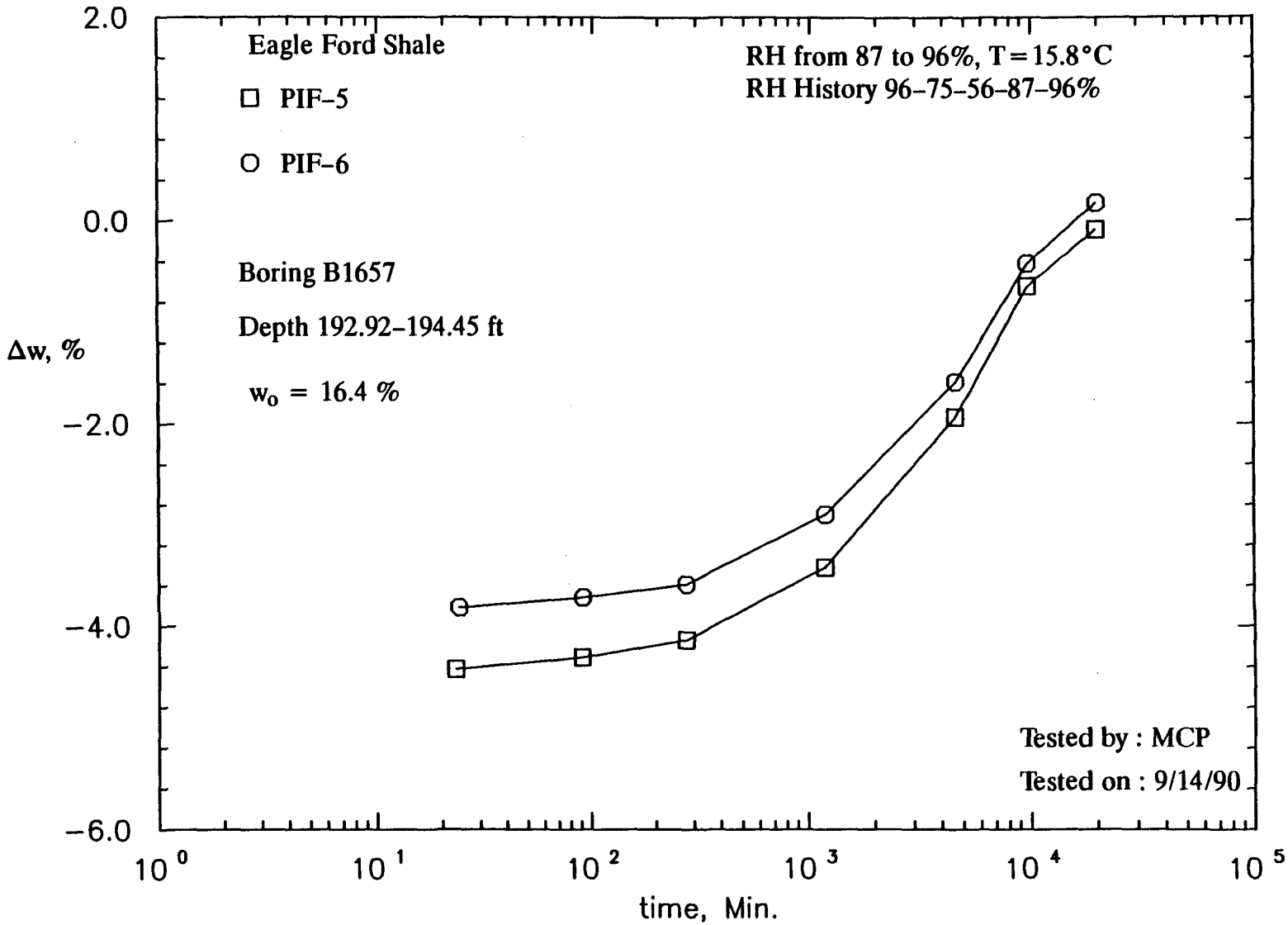


Fig. E3e Water Content Change - Log Time Relationship

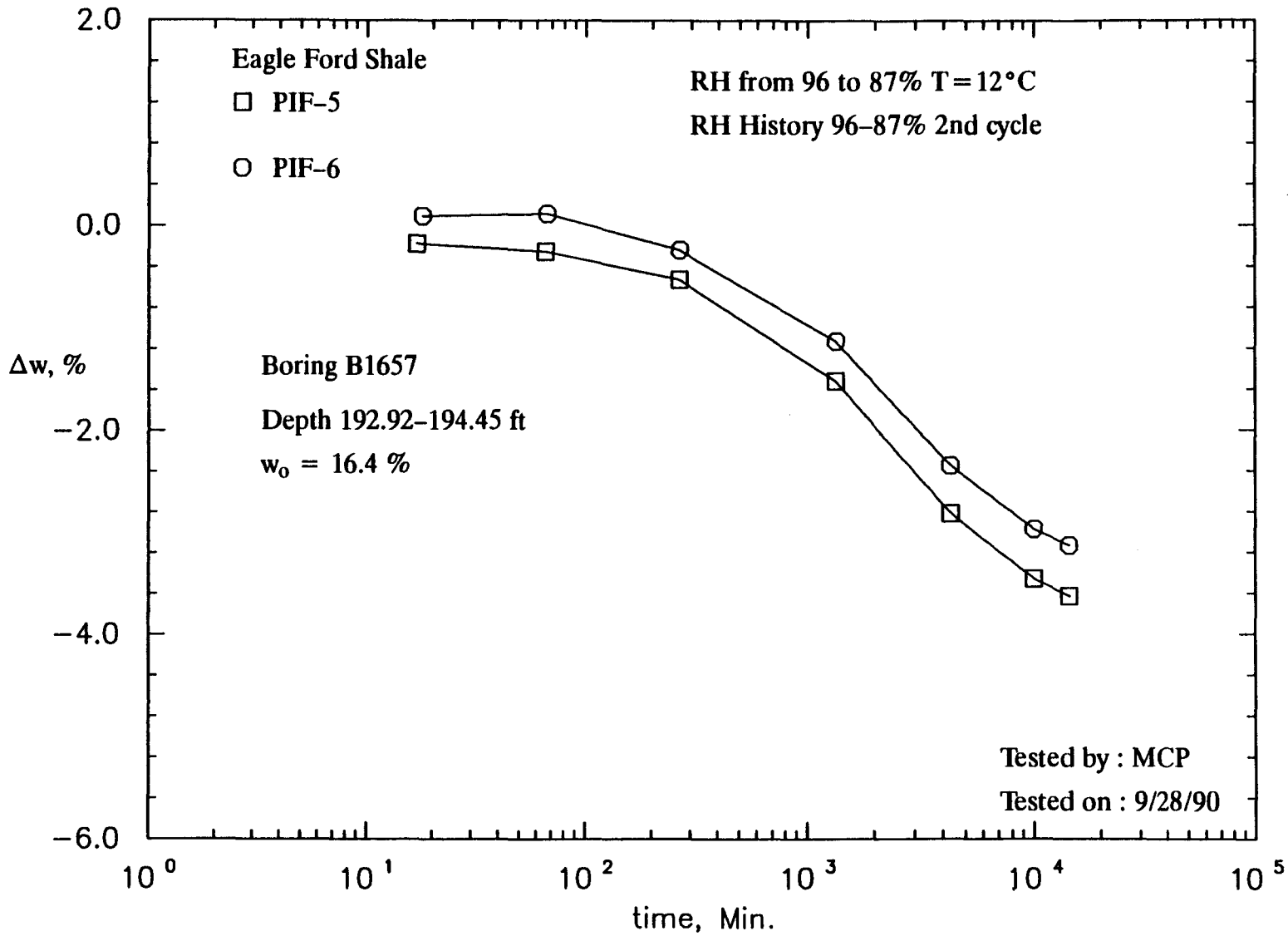


Fig. E3f Water Content Change – Log Time Relationship

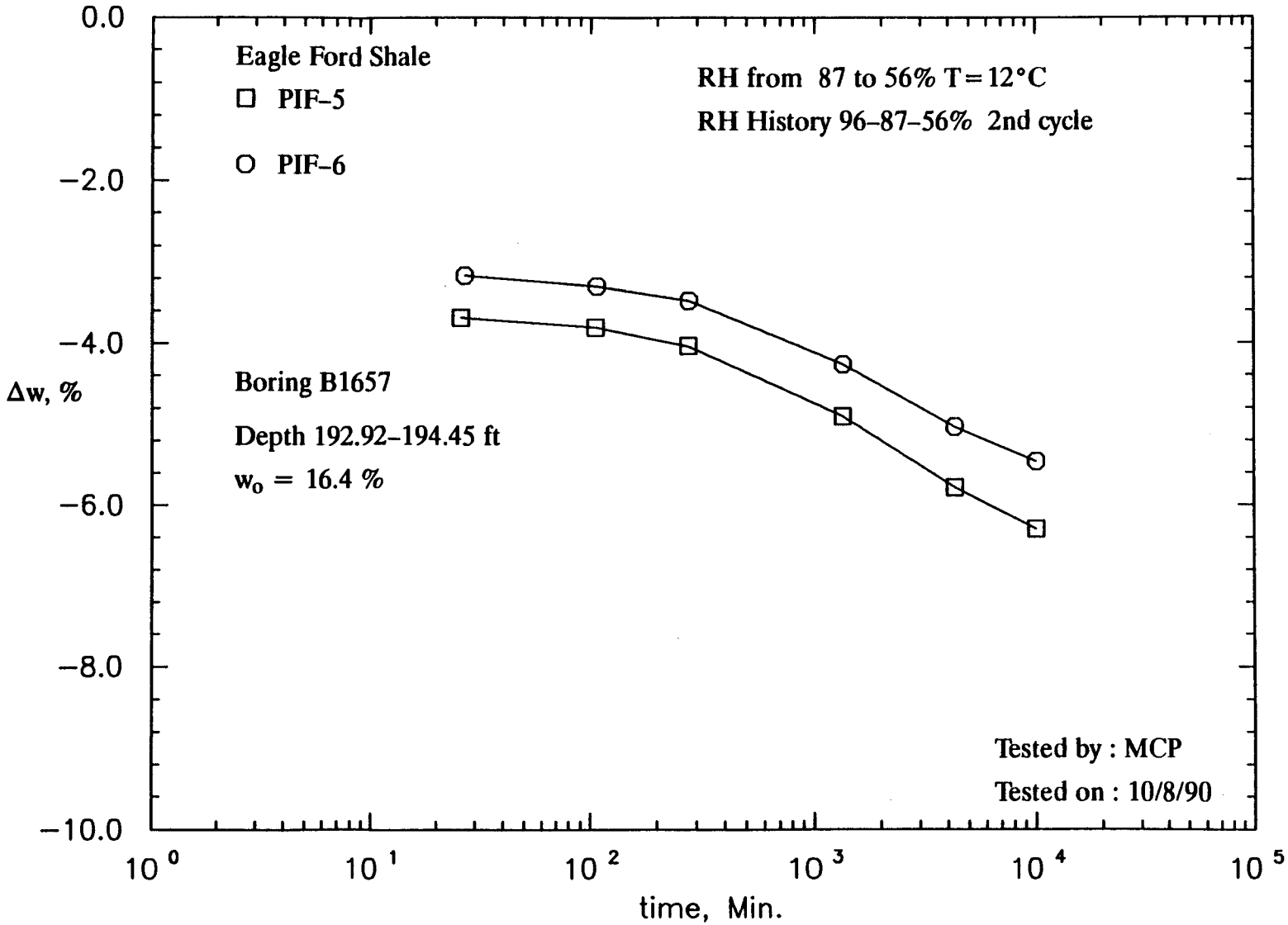


Fig. E3g Water Content Change – Log Time Relationship

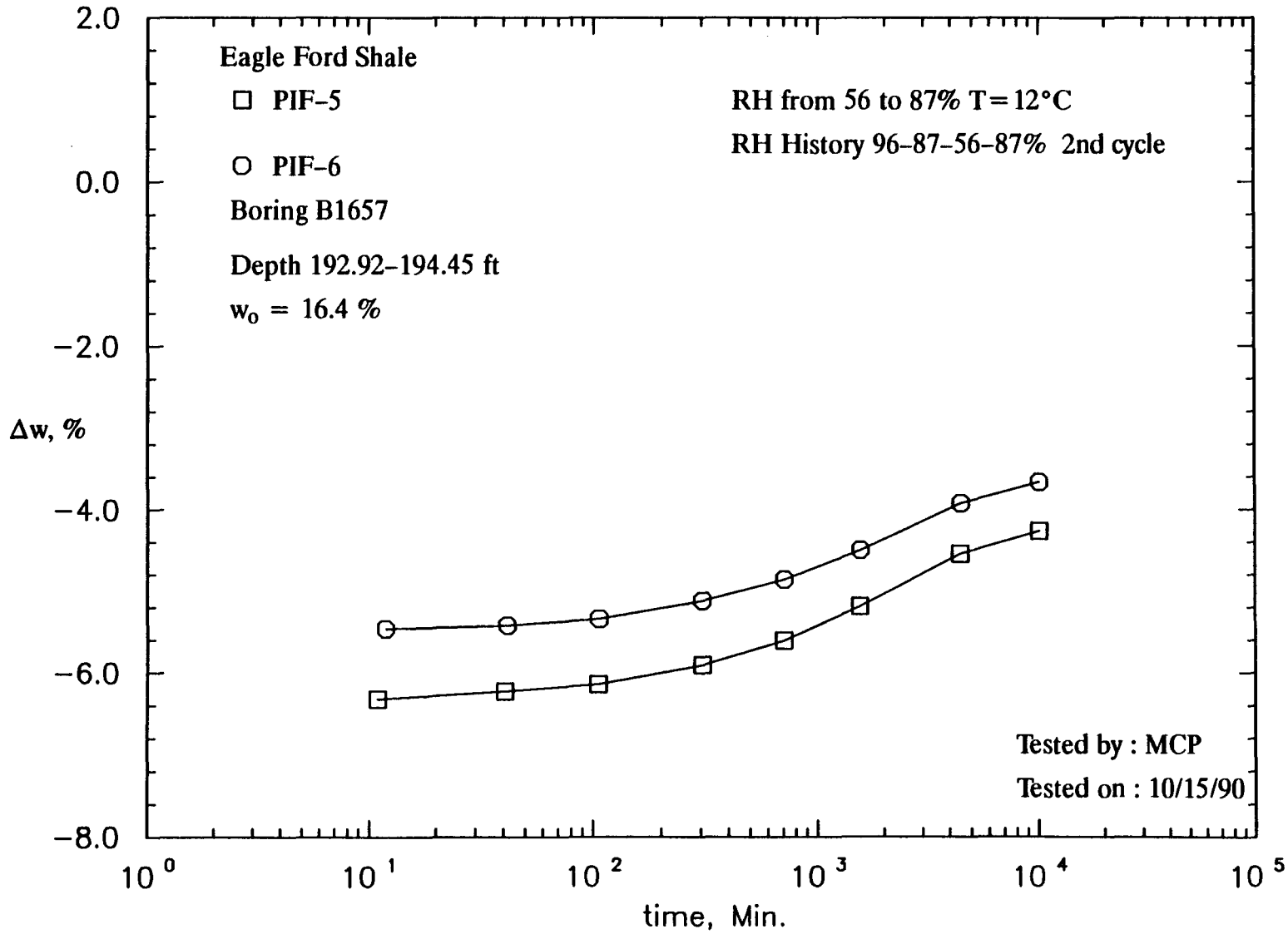


Fig. E3h Water Content Change - Log Time Relationship

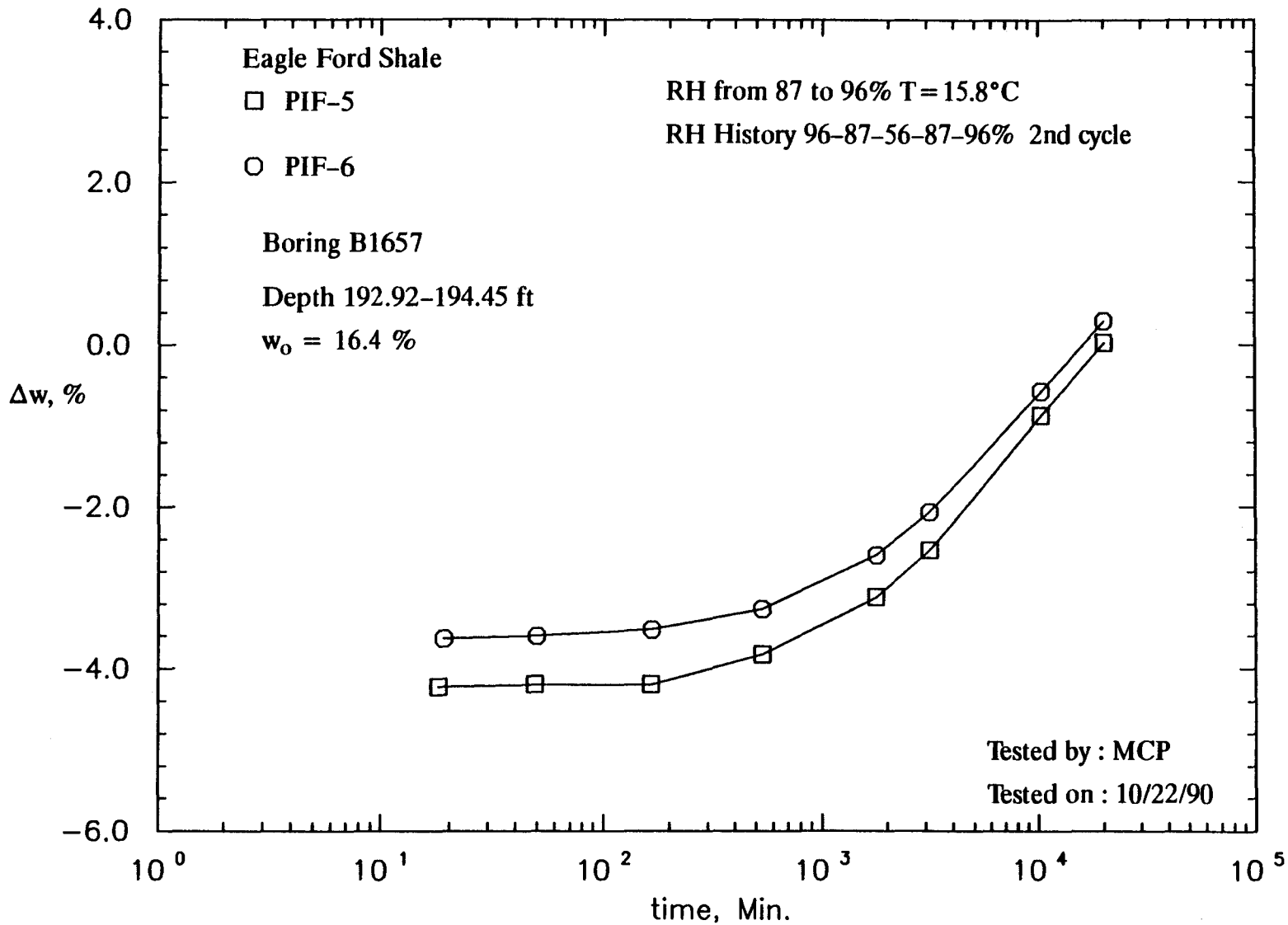


Fig. E3k Water Content Change – Log Time Relationship

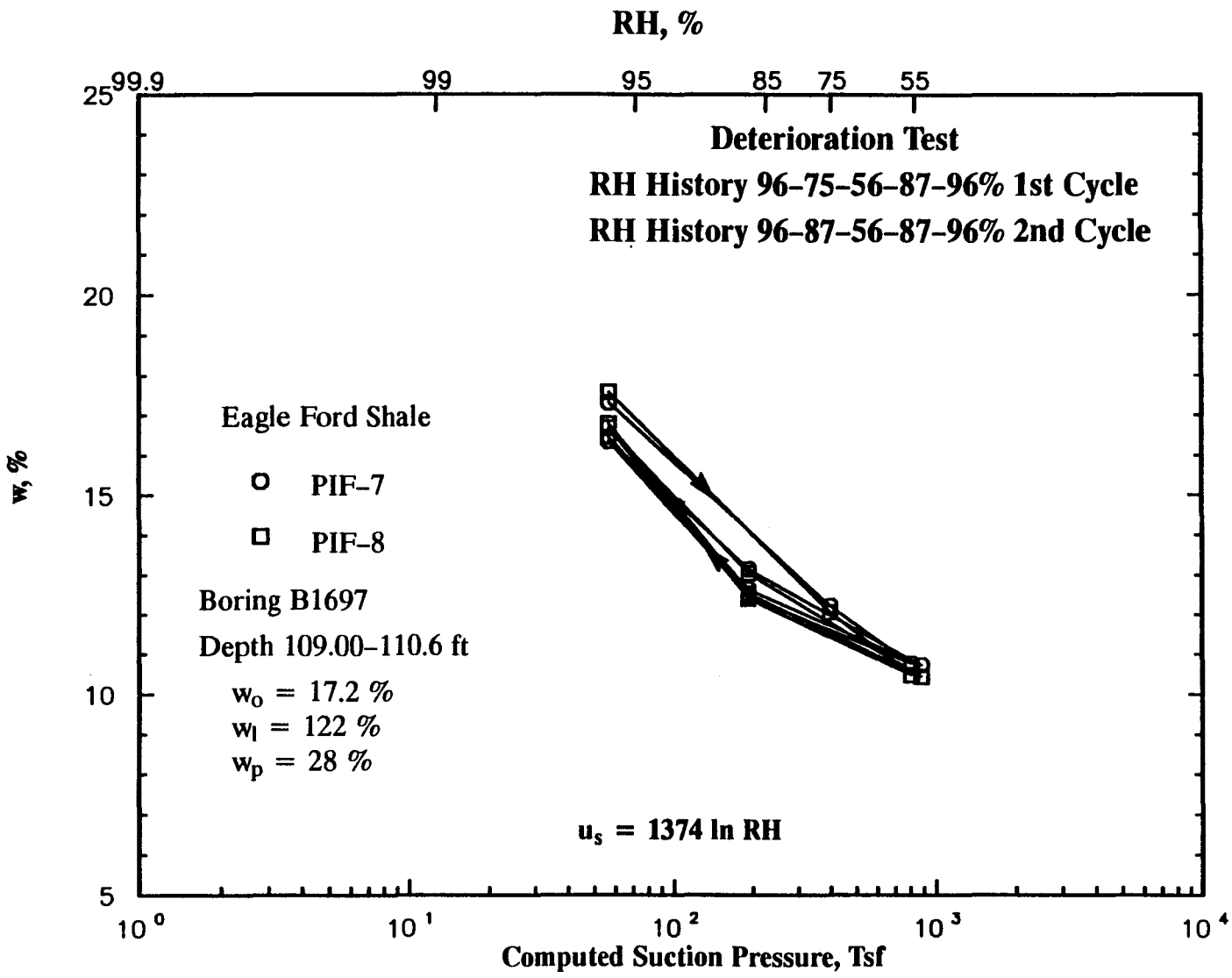


Fig. E4 Water Content – Relative Humidity Relationship

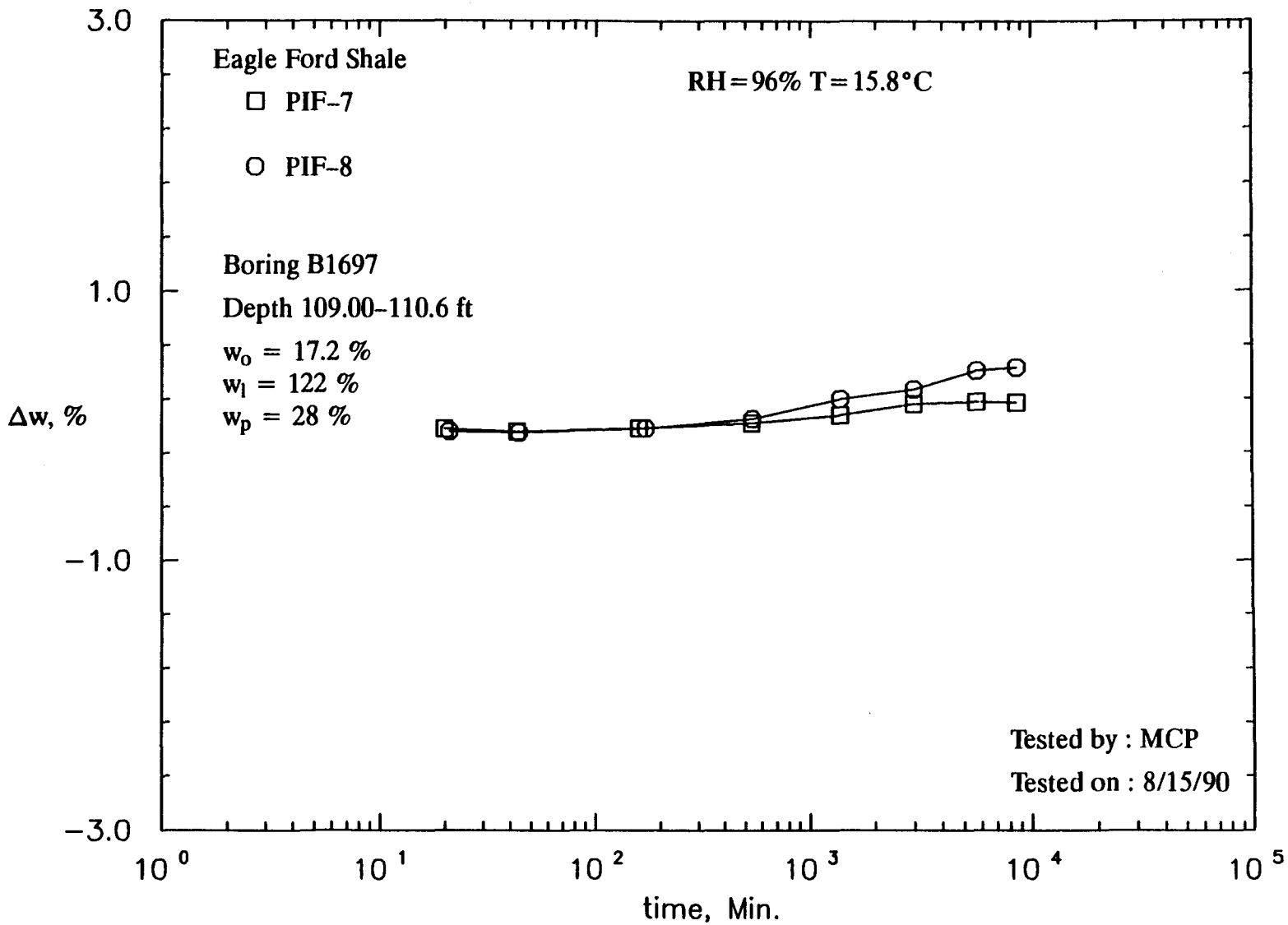


Fig. E4a Water Content Change – Log Time Relationship

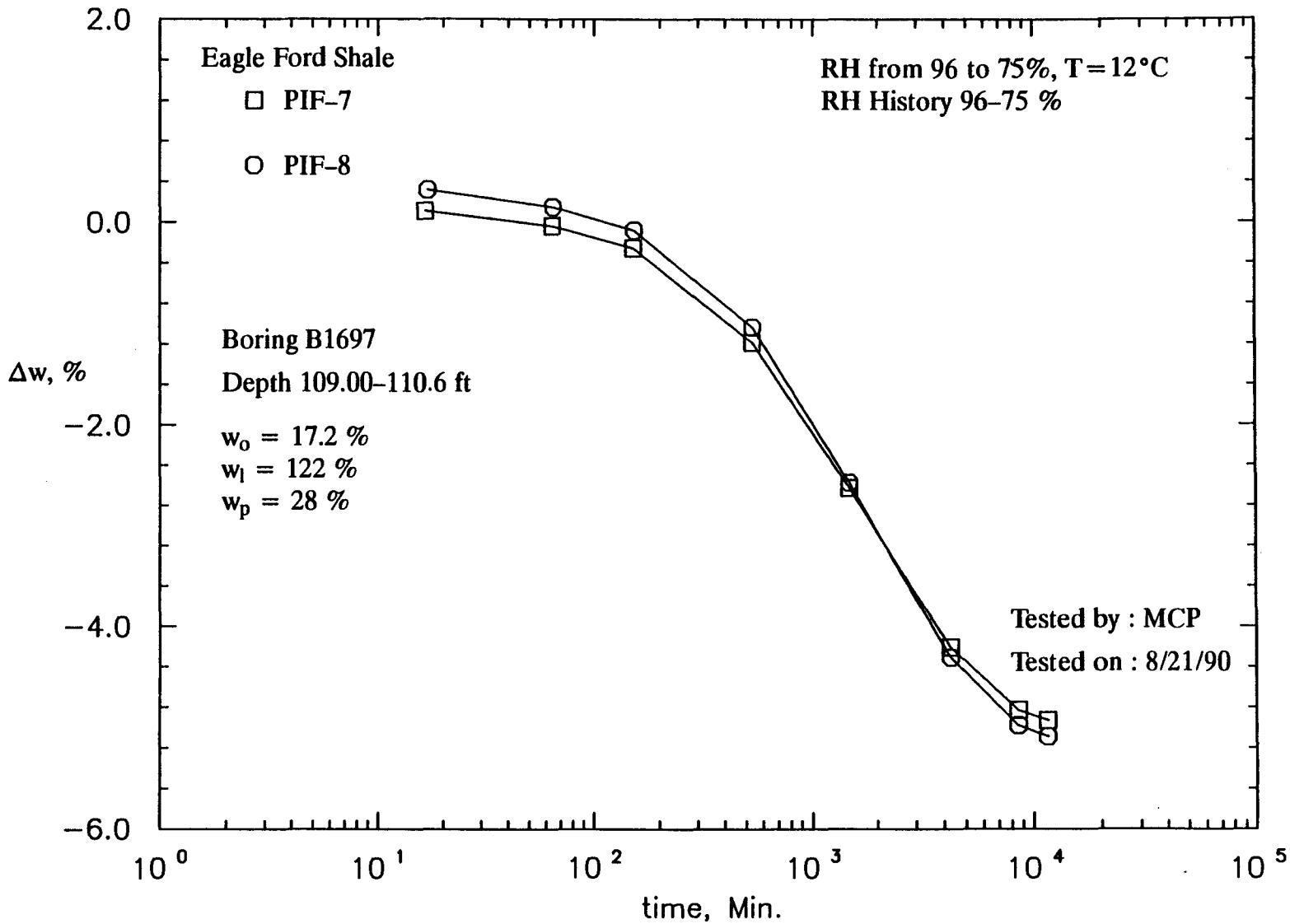


Fig. E4b Water Content Change – Log Time Relationship

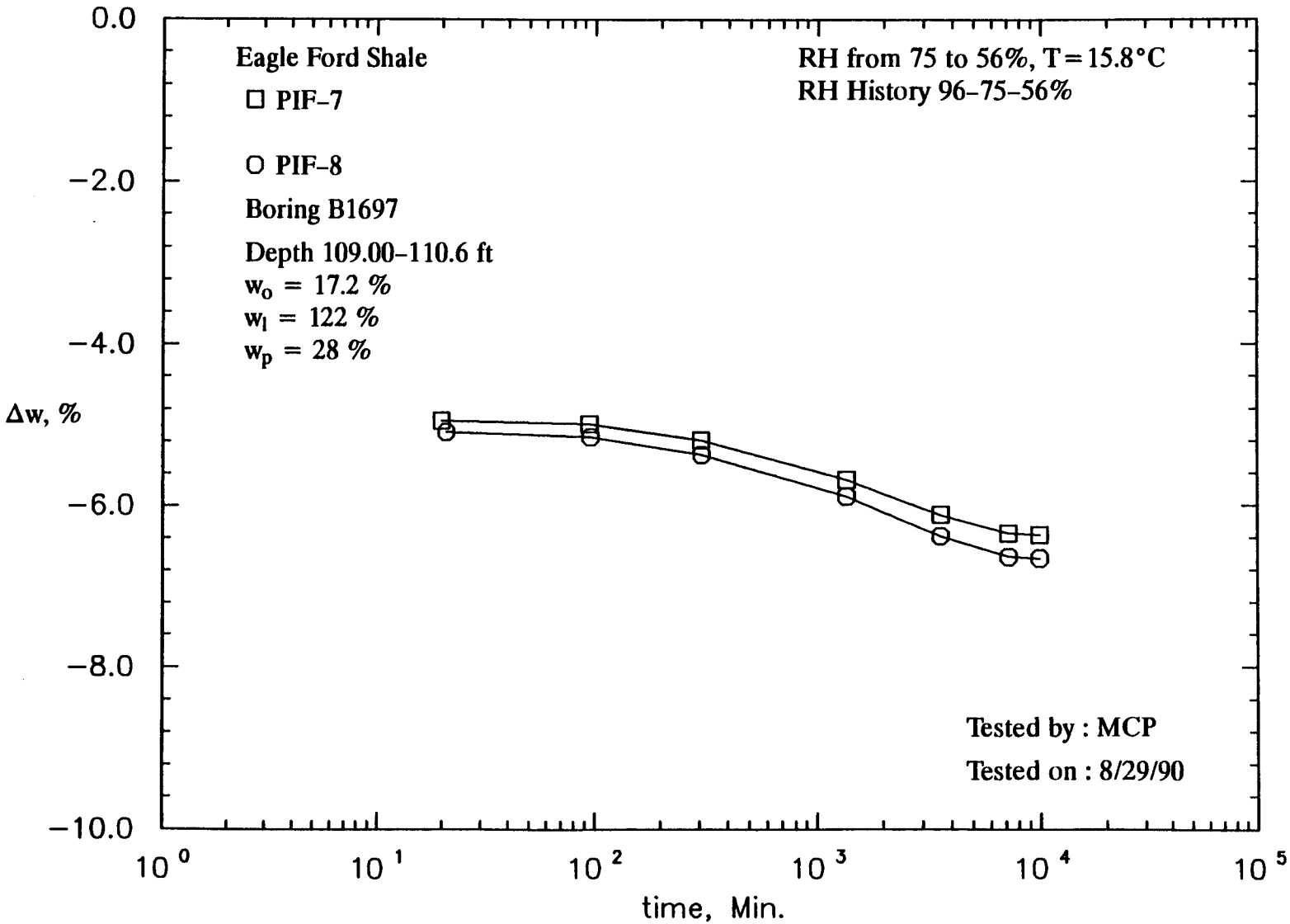


Fig. E4c Water Content Change – Log Time Relationship

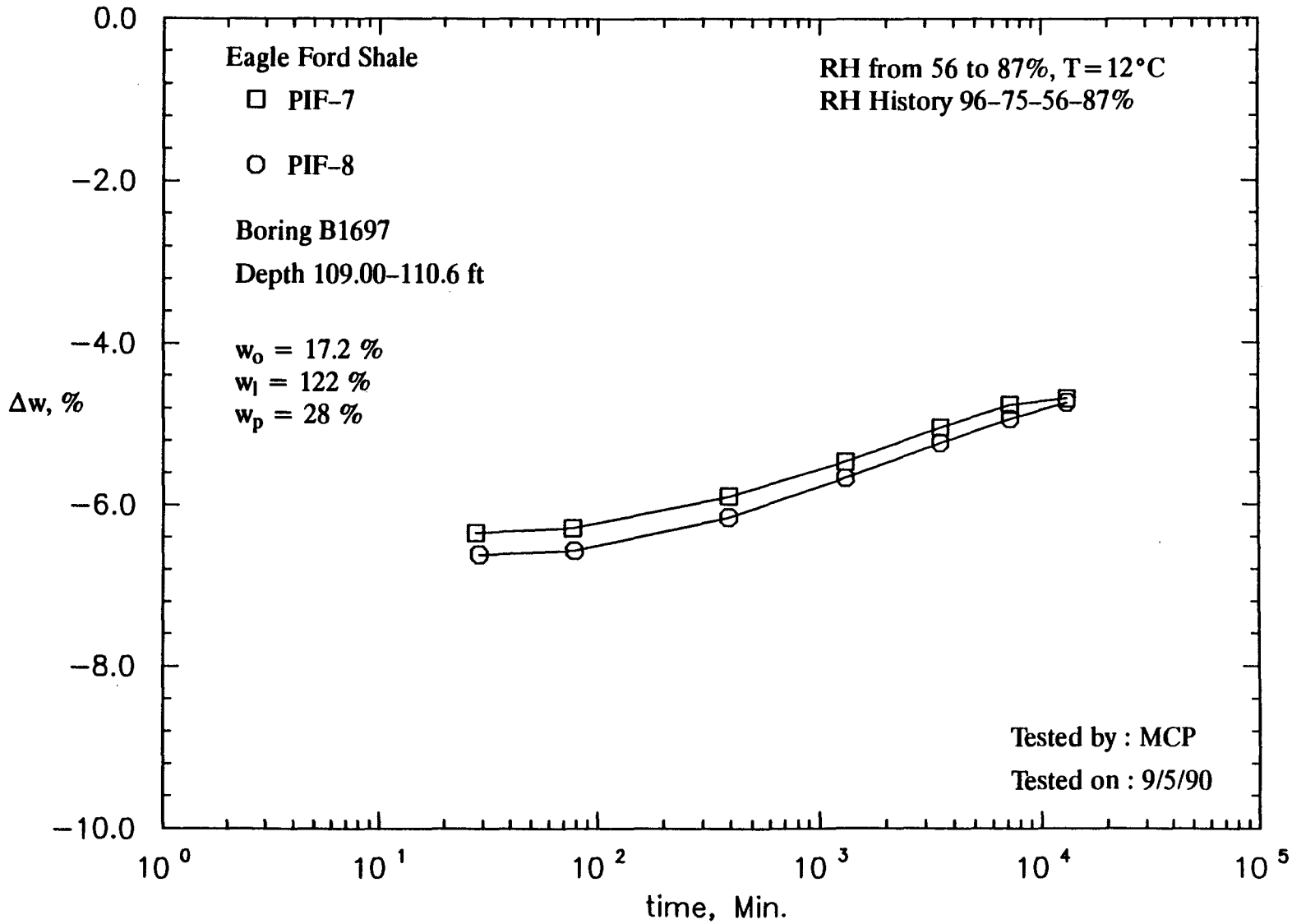


Fig. E4d Water Content Change - Log Time Relationship

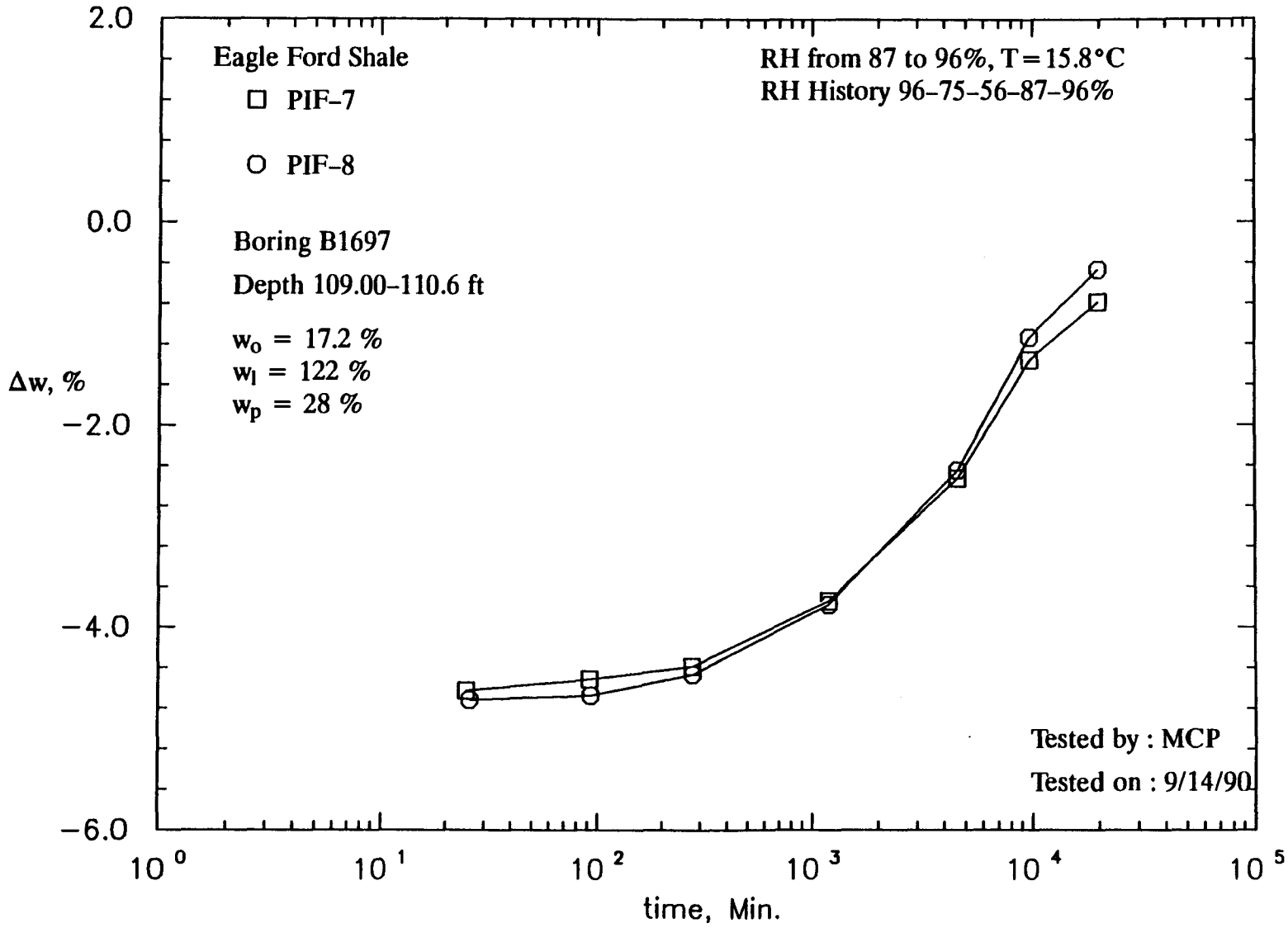


Fig. E4e Water Content Change - Log Time Relationship

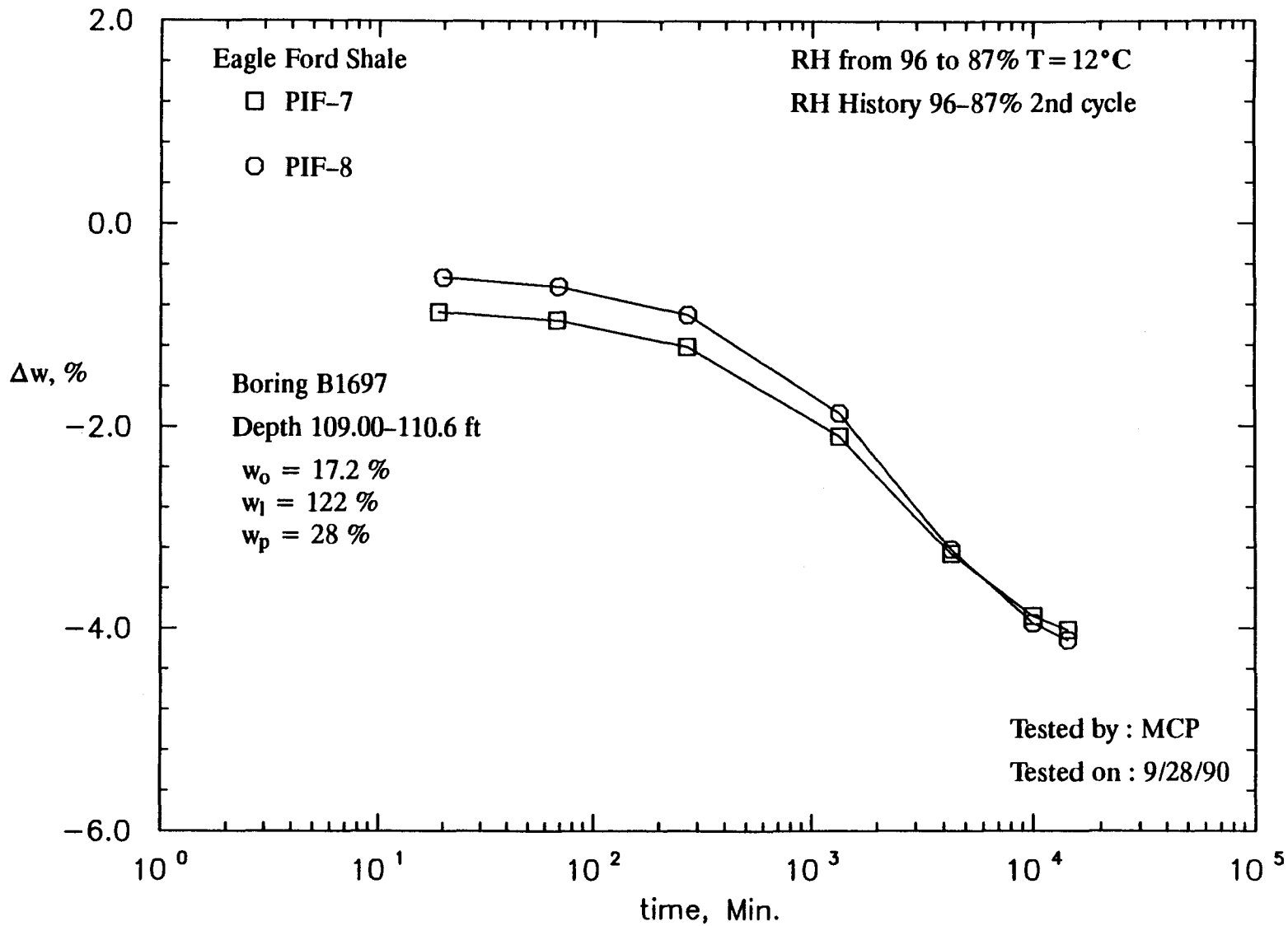


Fig. E4f Water Content Change – Log Time Relationship

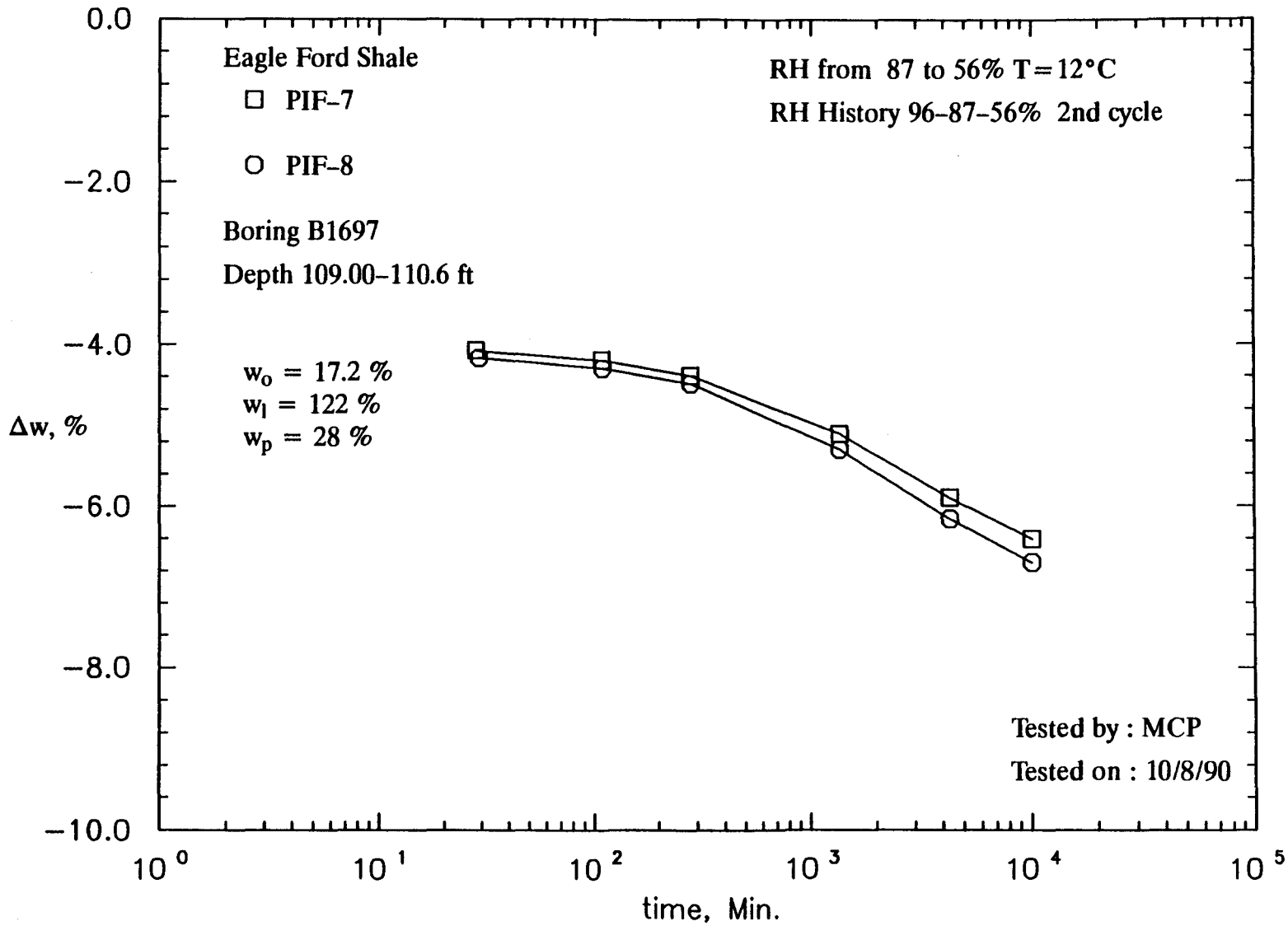


Fig. E4g Water Content Change - Log Time Relationship

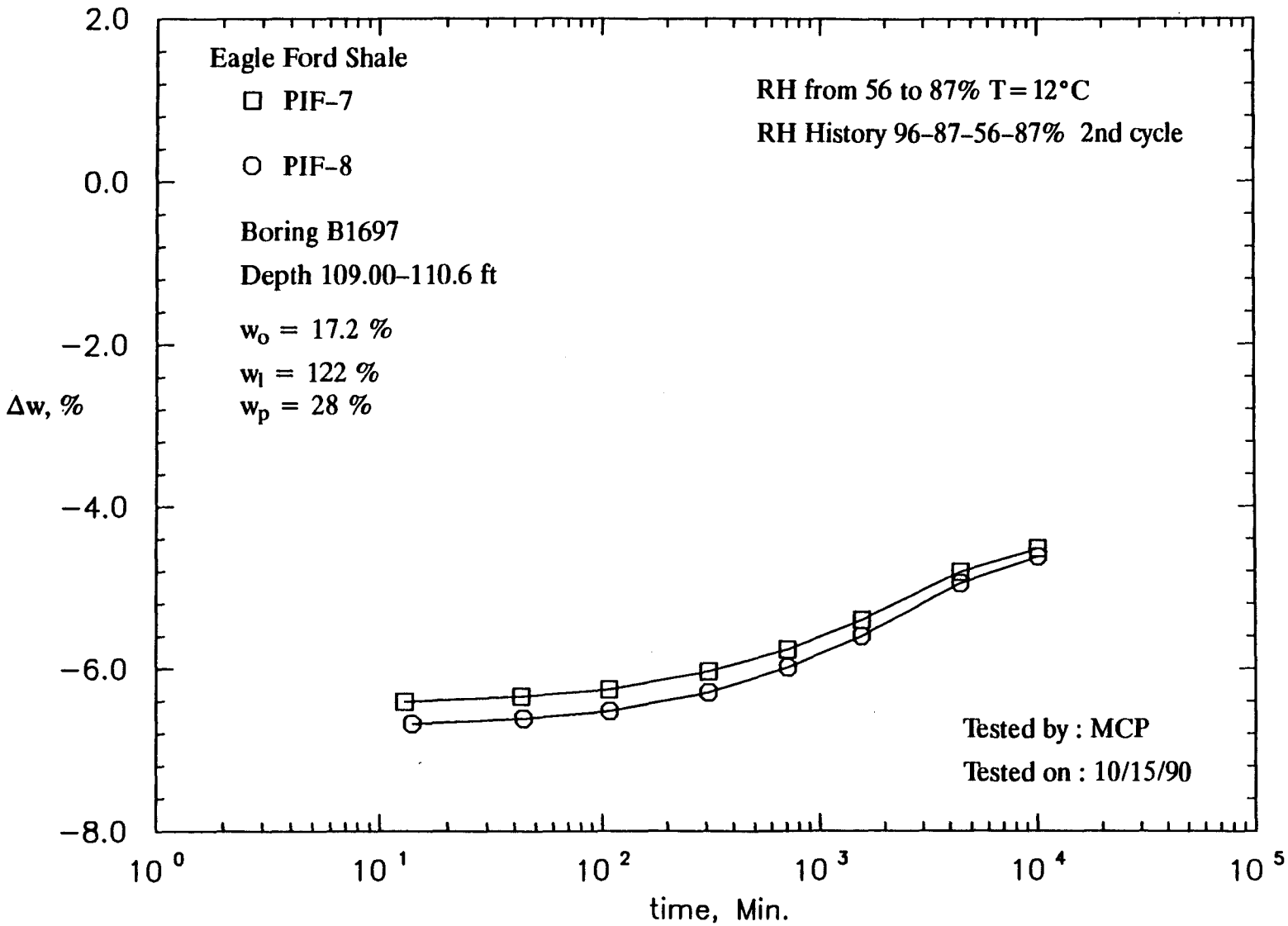


Fig. E4h Water Content Change - Log Time Relationship

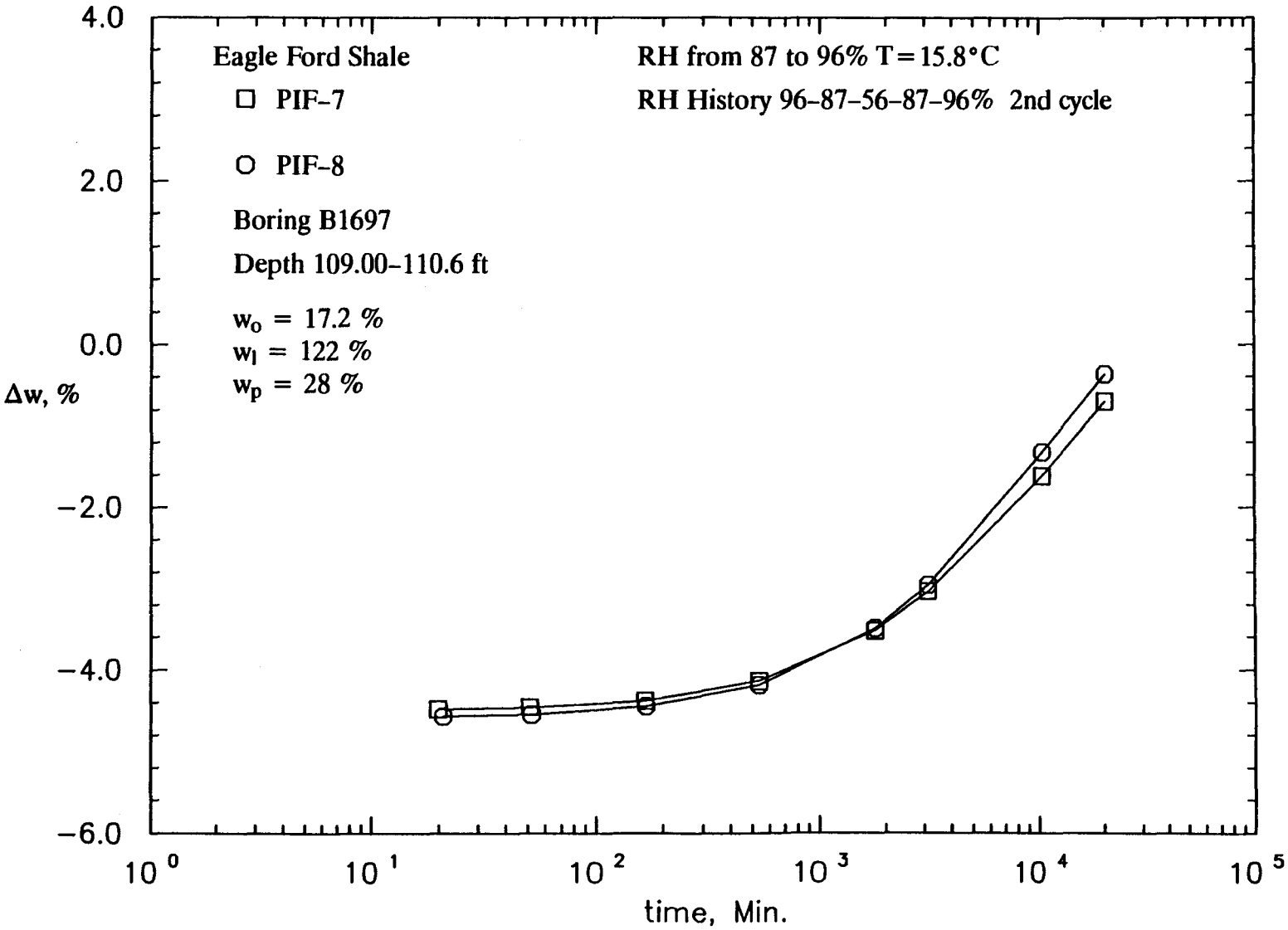


Fig. E4k Water Content Change – Log Time Relationship

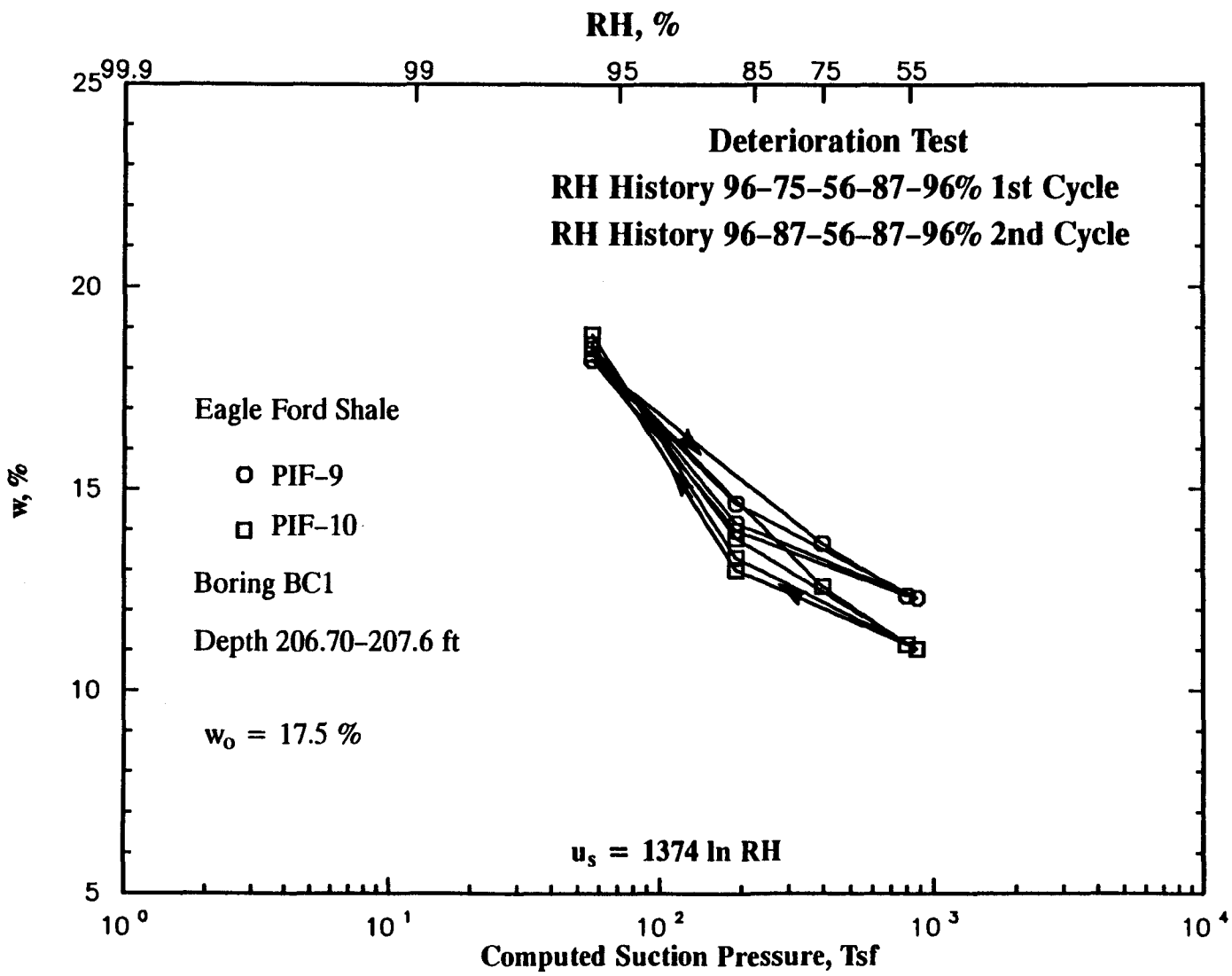


Fig. E5 Water Content – Relative Humidity Relationship

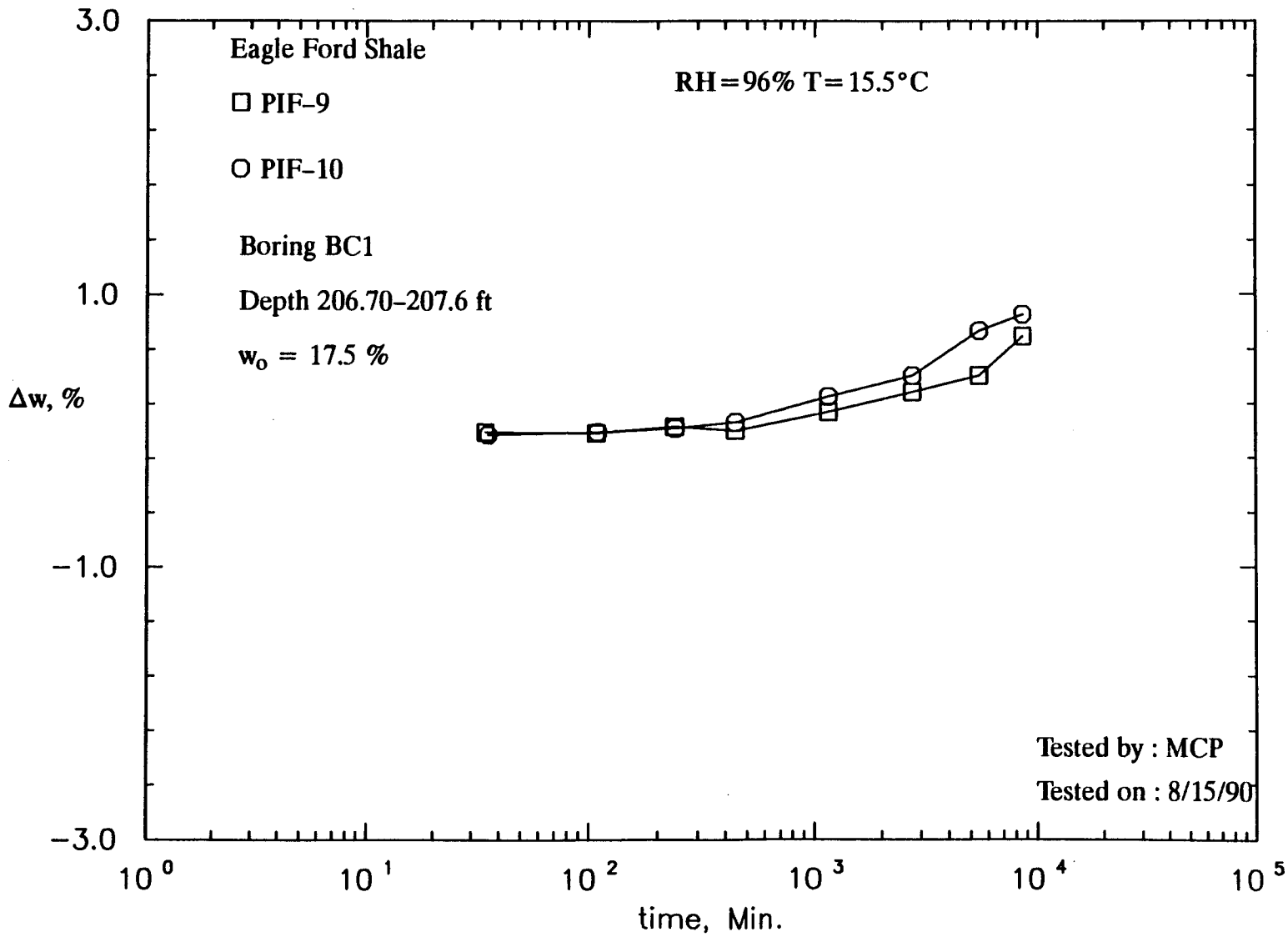


Fig. E5a Water Content Change – Log Time Relationship

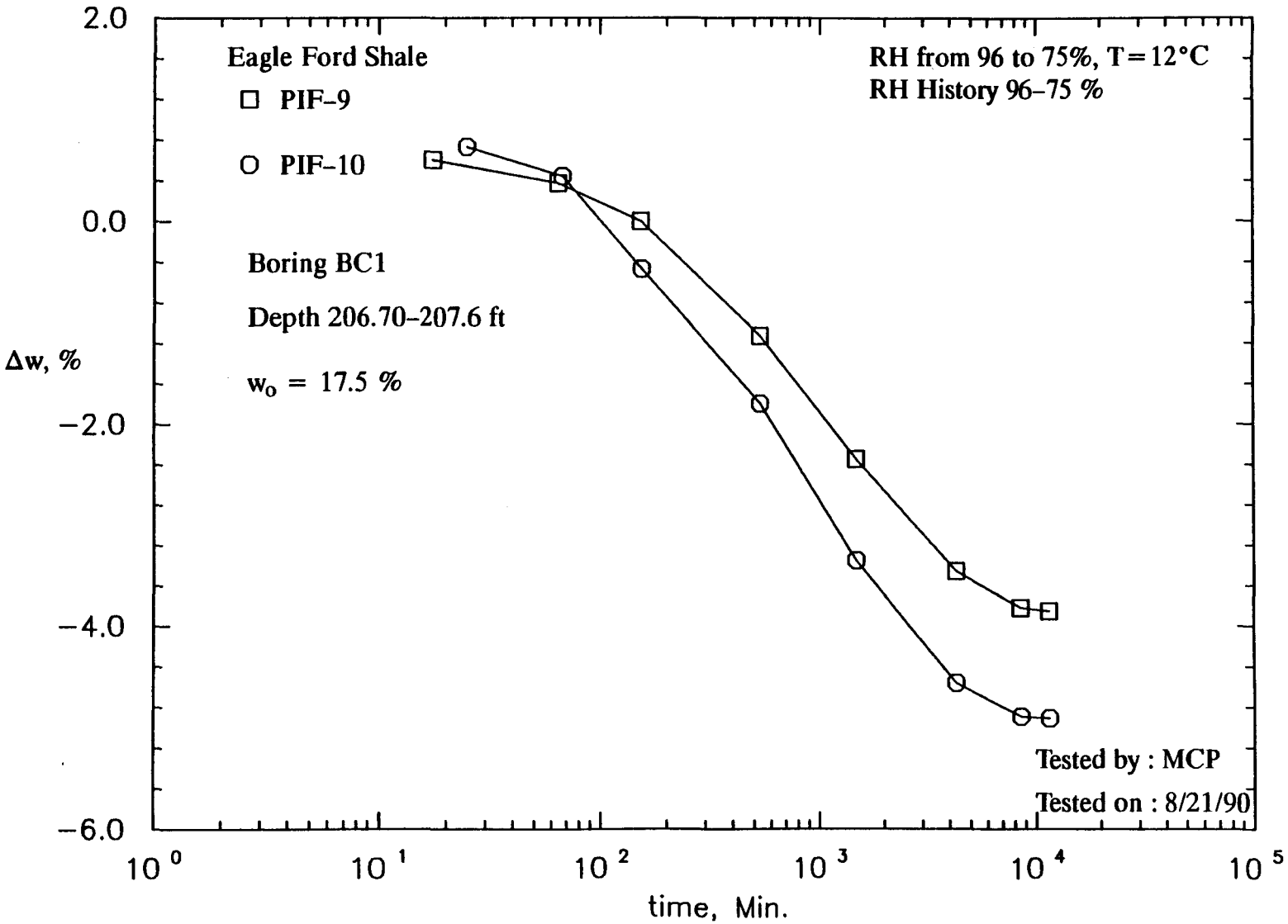


Fig. E5b Water Content Change - Log Time Relationship

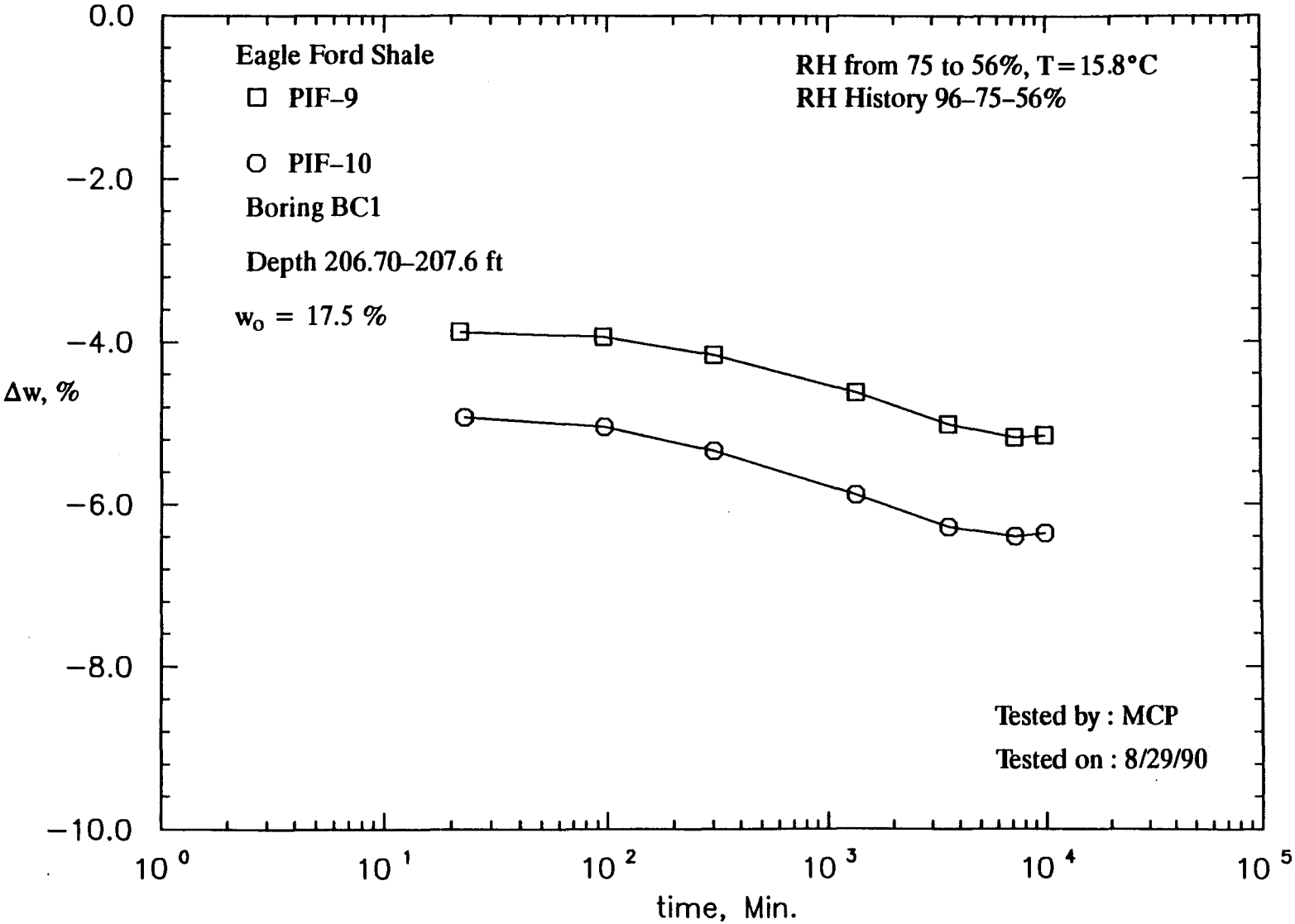


Fig. E5c Water Content Change – Log Time Relationship

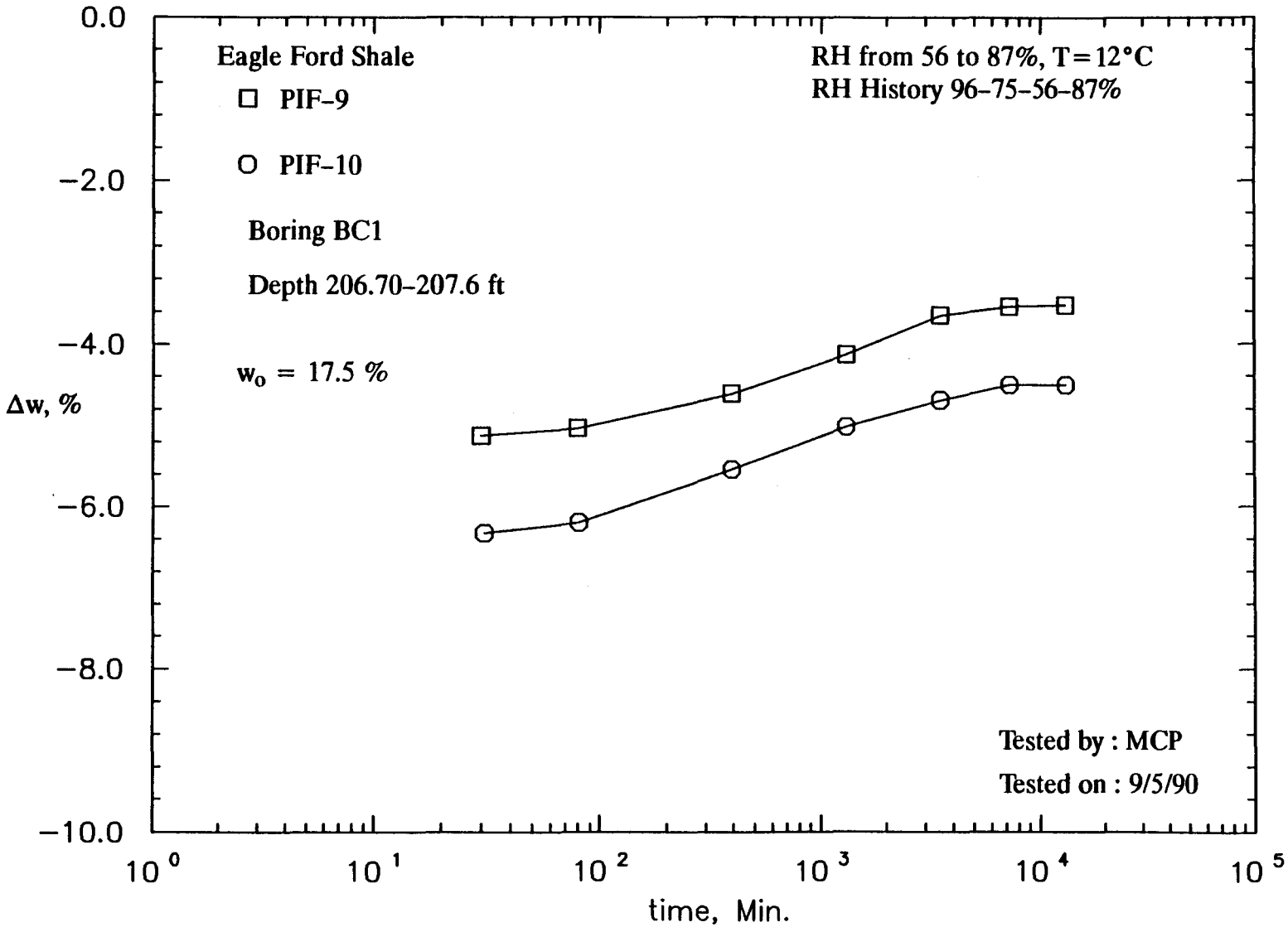


Fig. E5d Water Content Change – Log Time Relationship

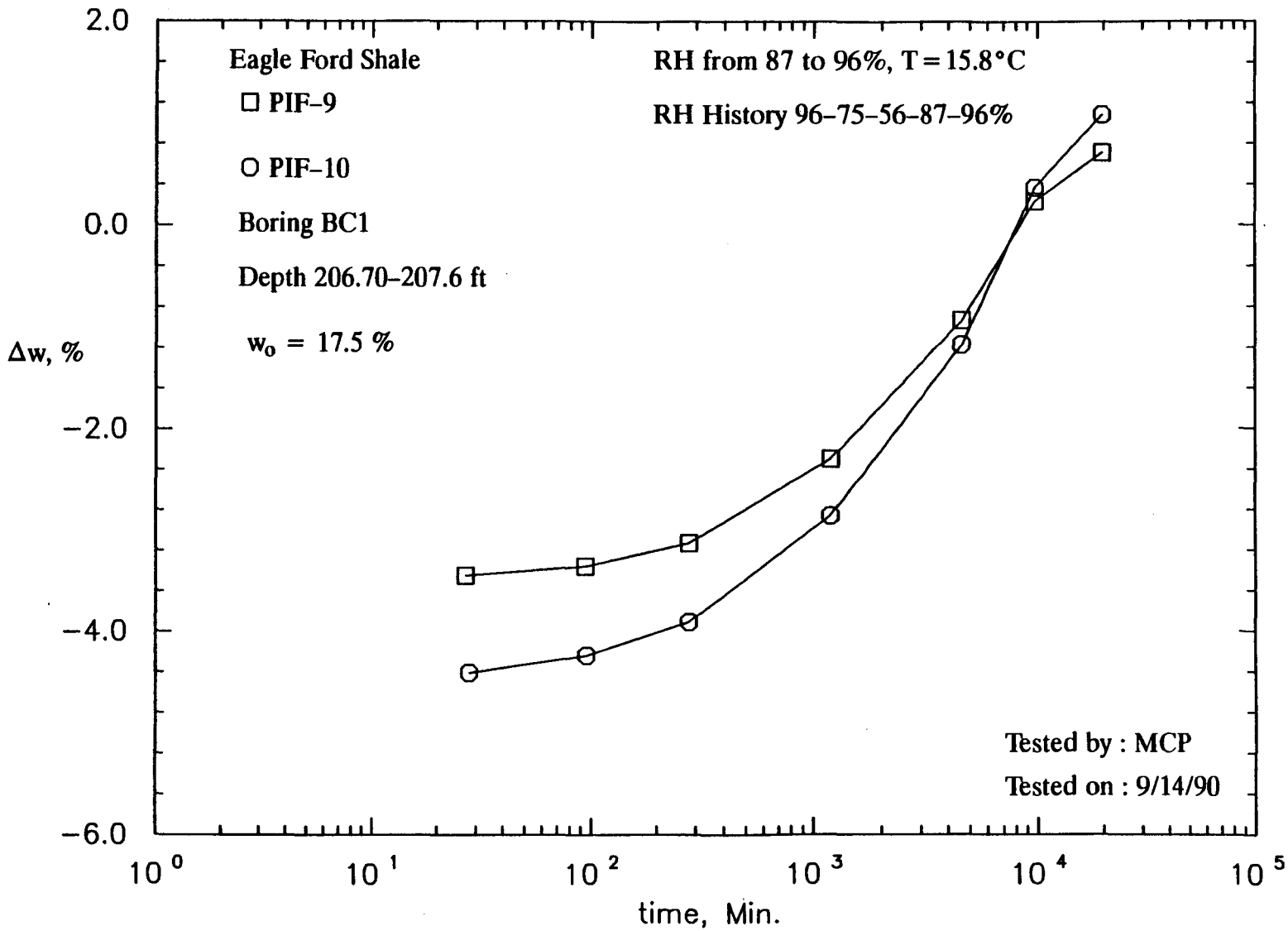


Fig. E5e Water Content Change – Log Time Relationship

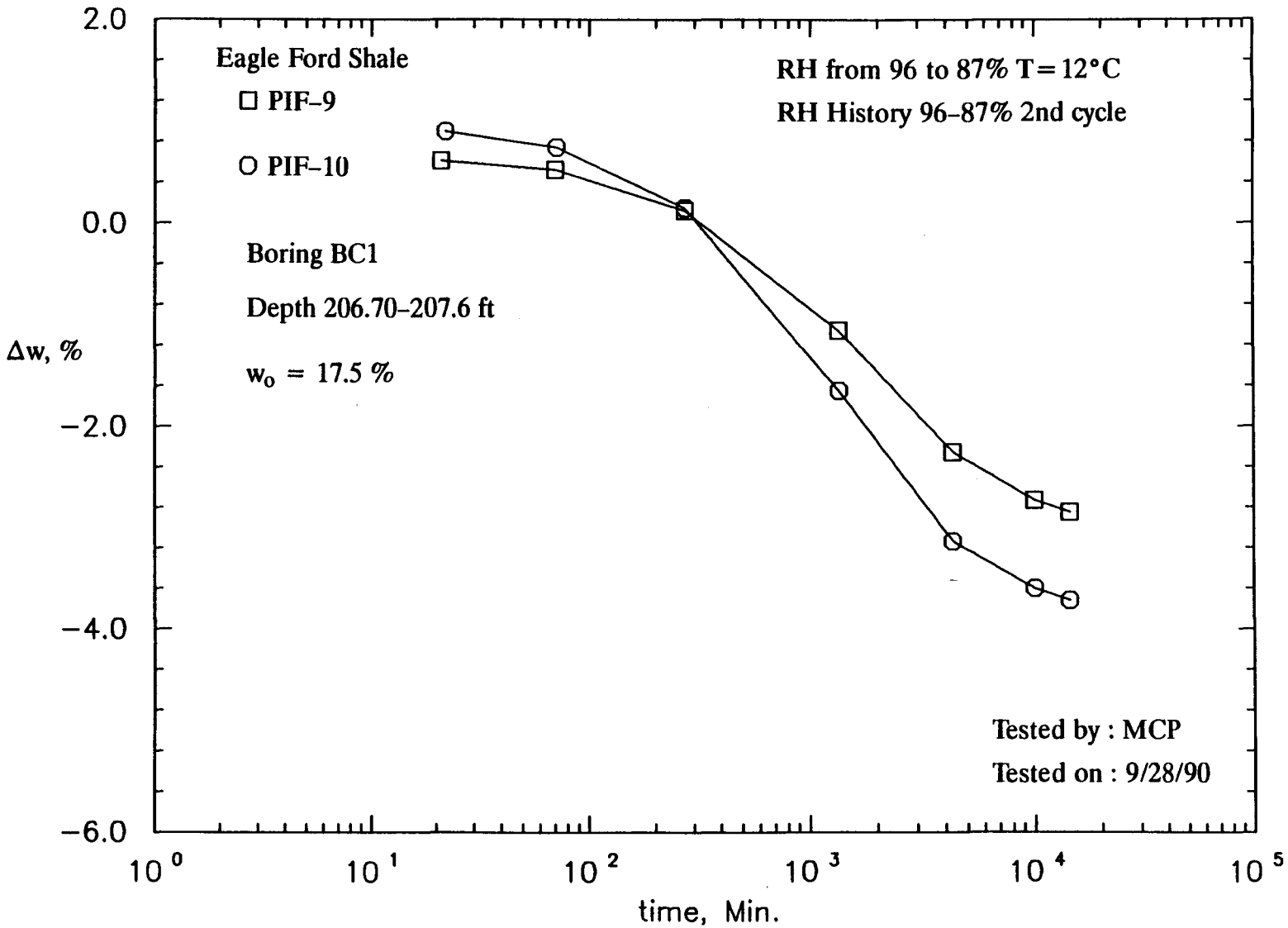


Fig. E5f Water Content Change – Log Time Relationship

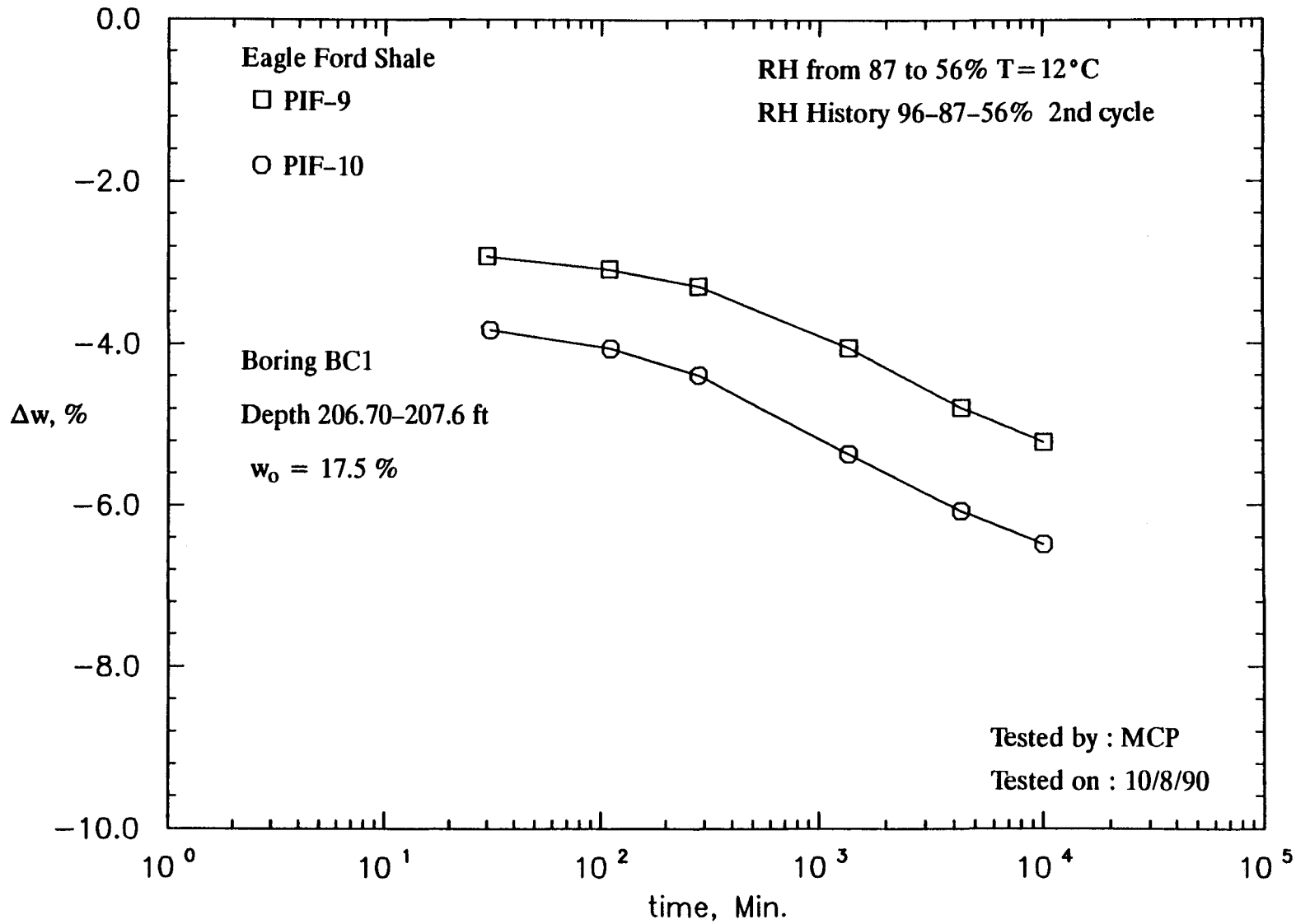


Fig. E5g Water Content Change - Log Time Relationship

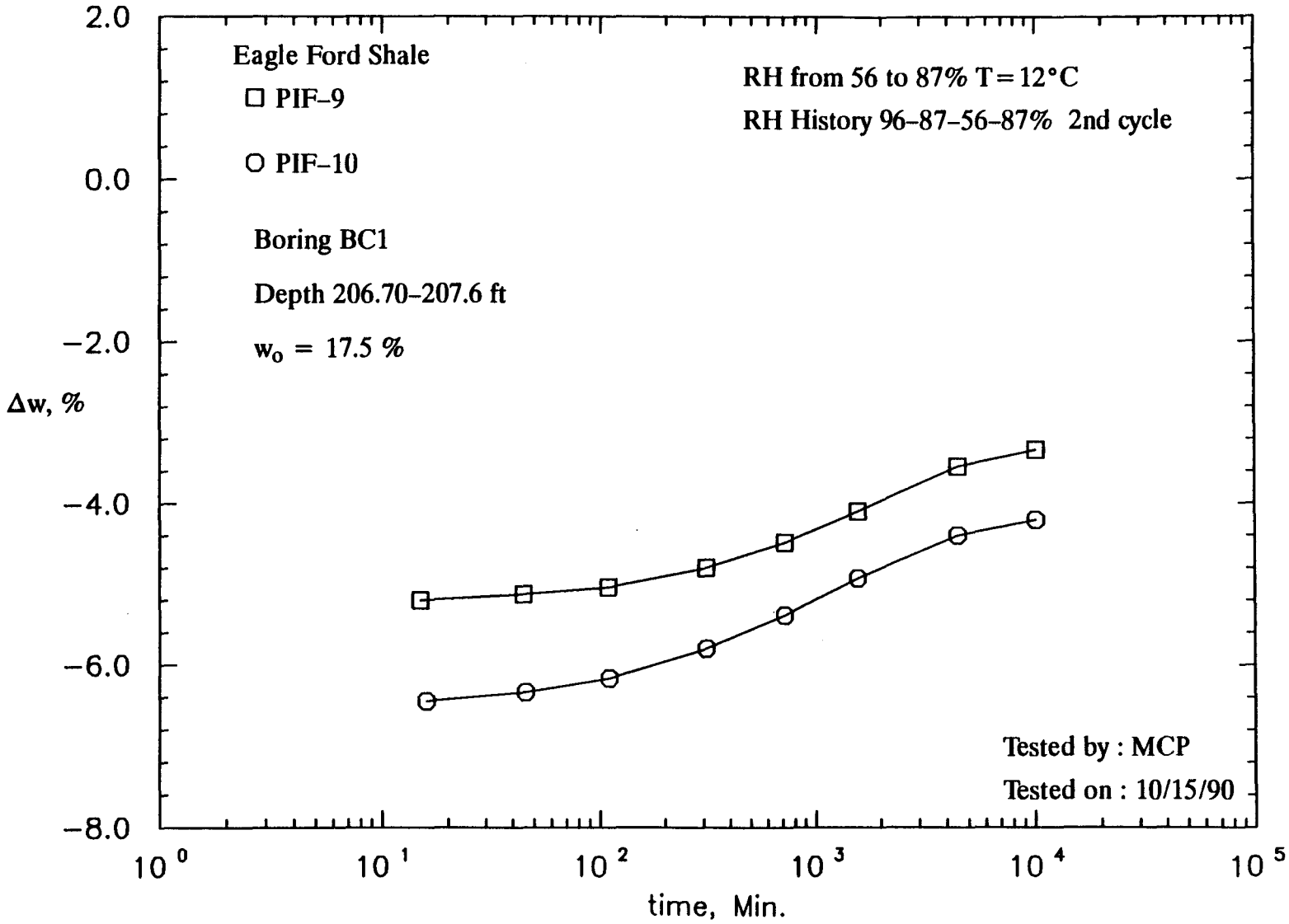


Fig. E5h Water Content Change – Log Time Relationship

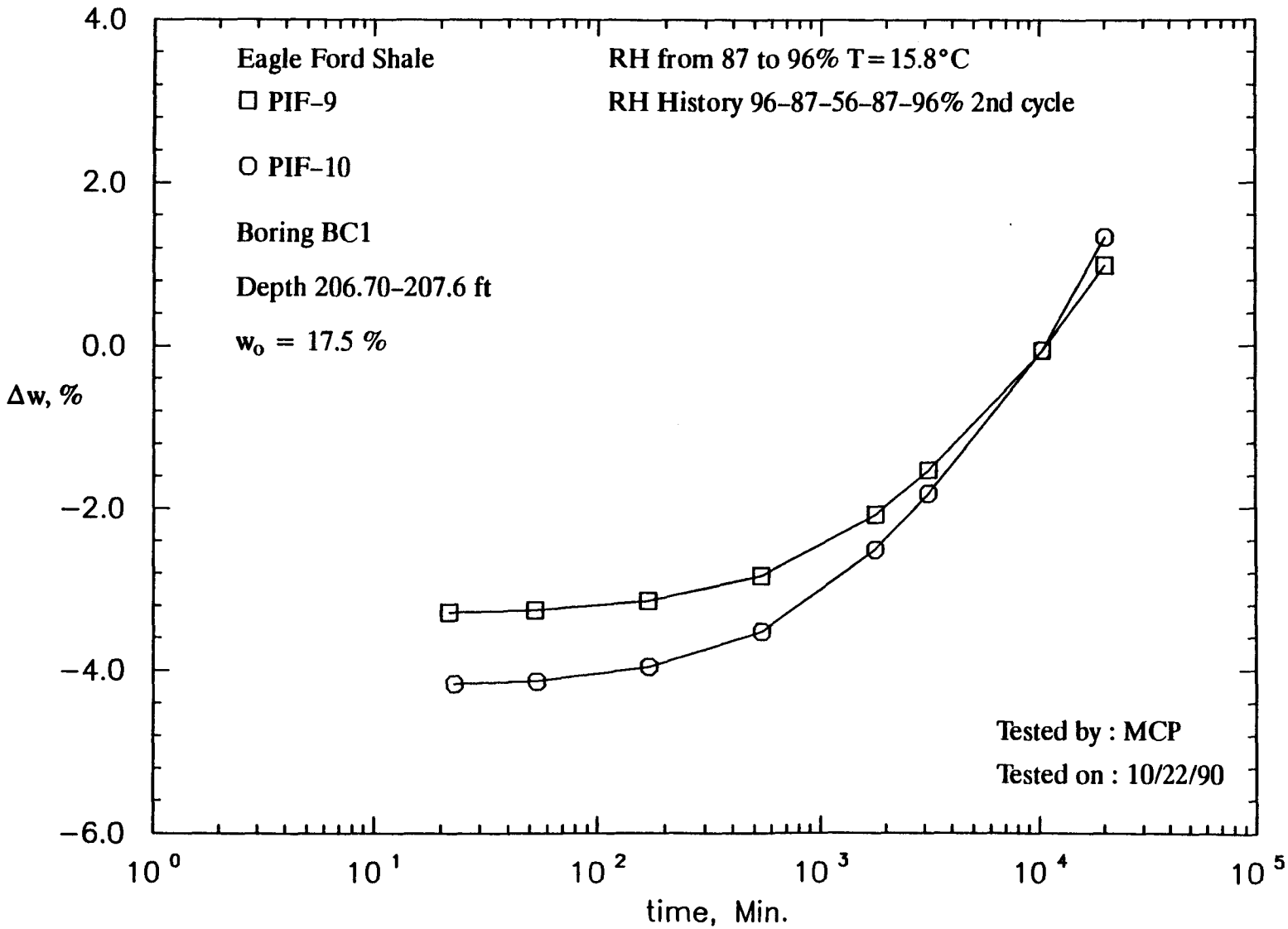


Fig. E5k Water Content Change - Log Time Relationship

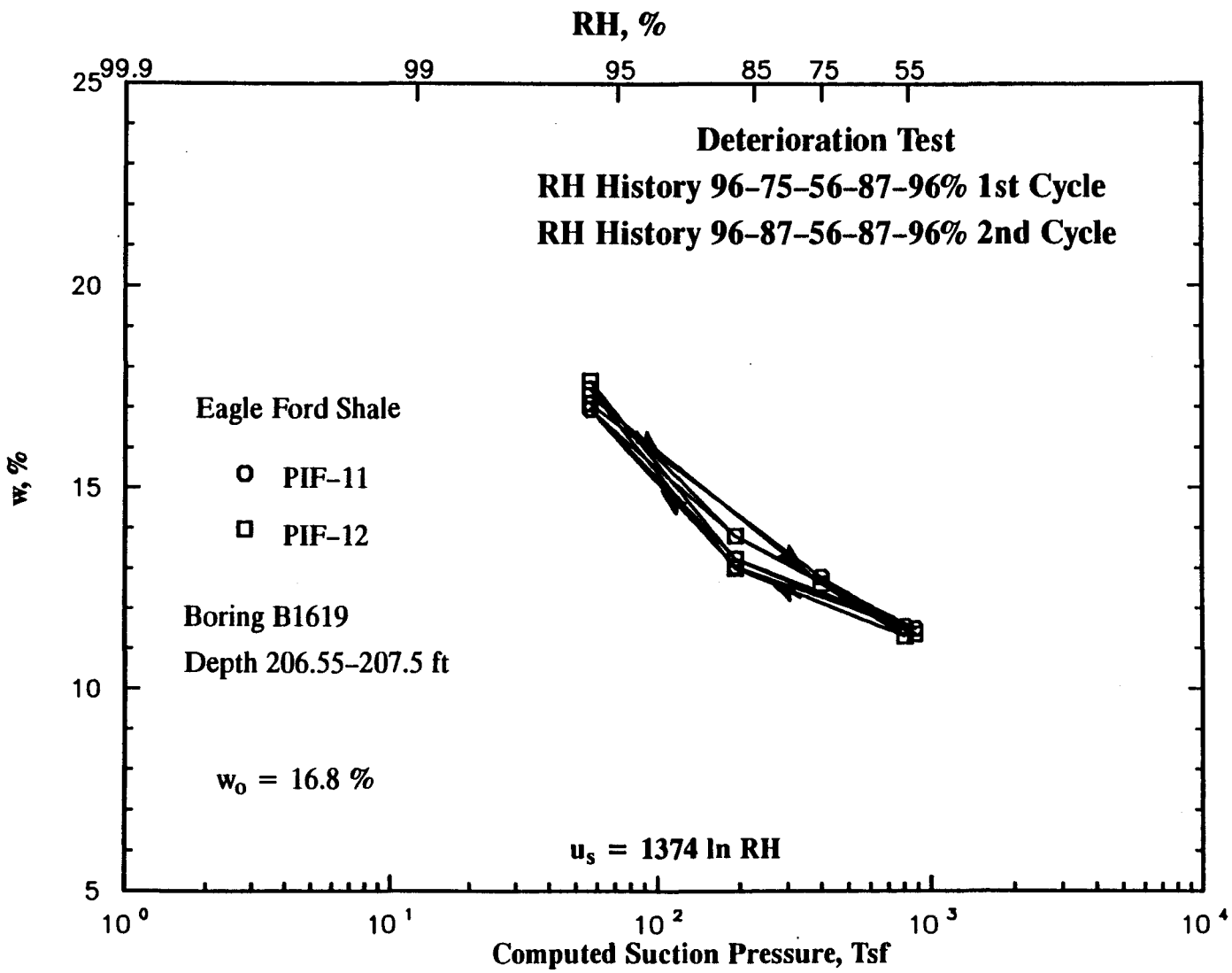


Fig. E6 Water Content – Relative Humidity Relationship

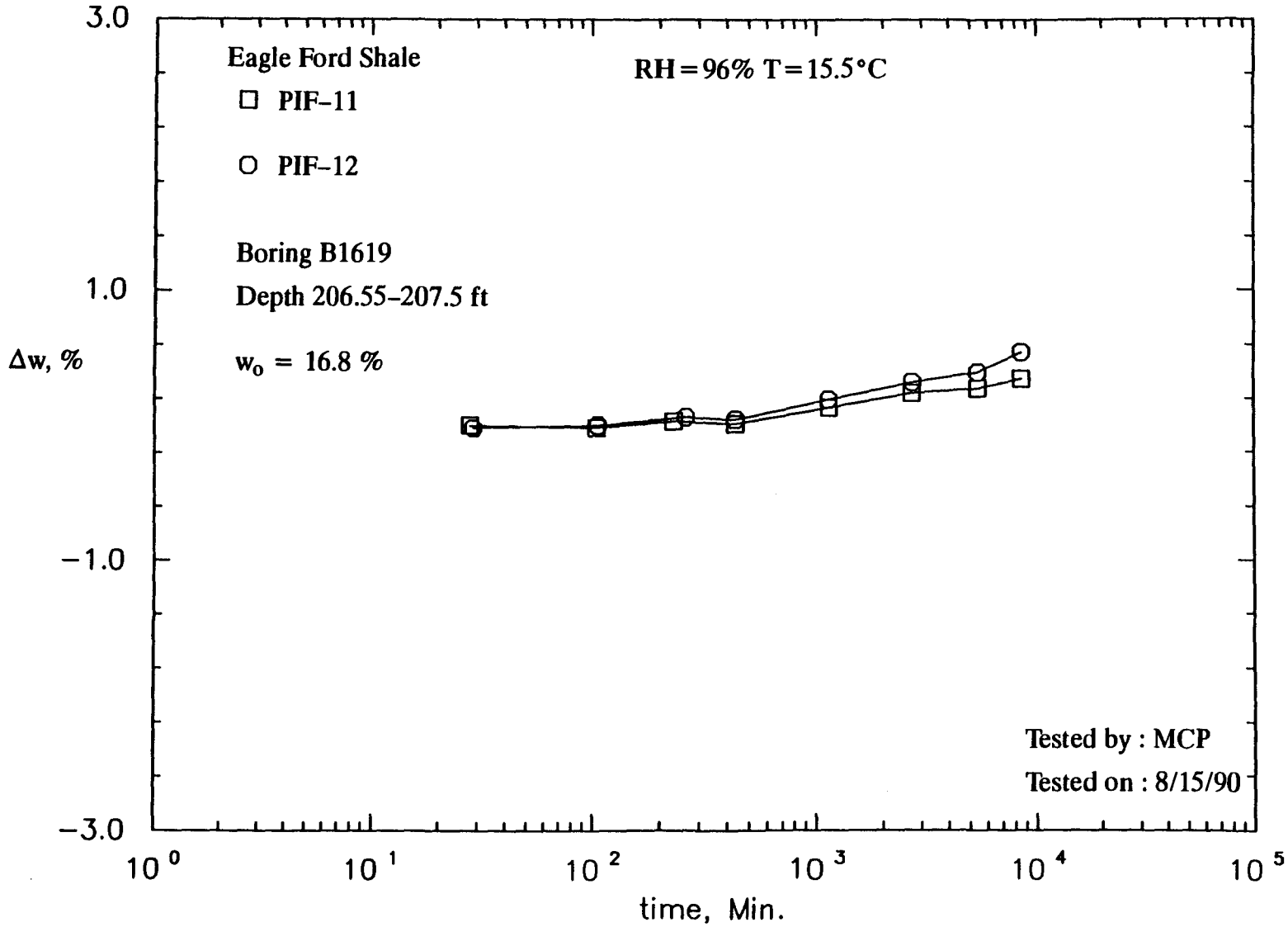


Fig. E6a Water Content Change – Log Time Relationship

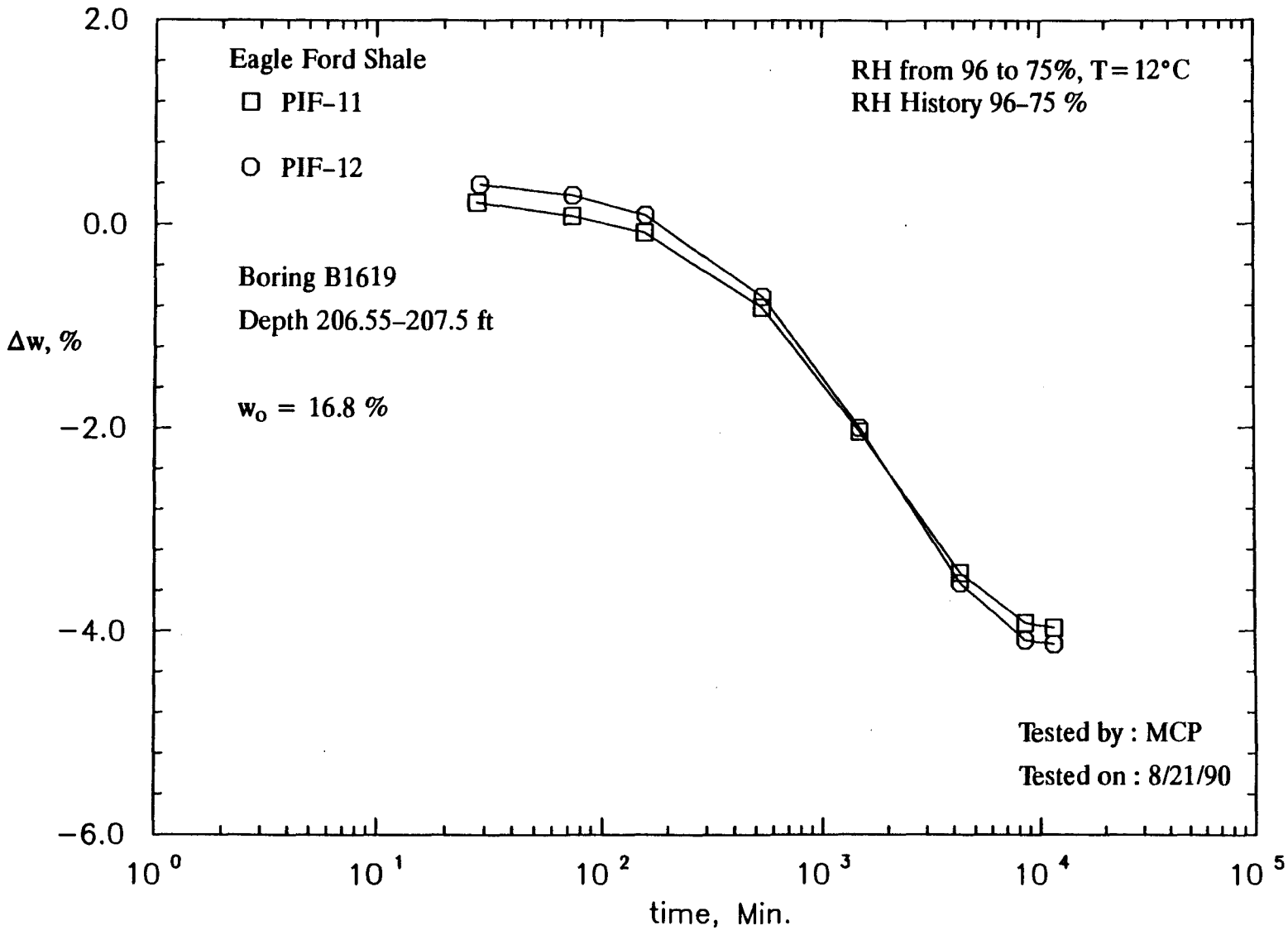


Fig. E6b Water Content Change – Log Time Relationship

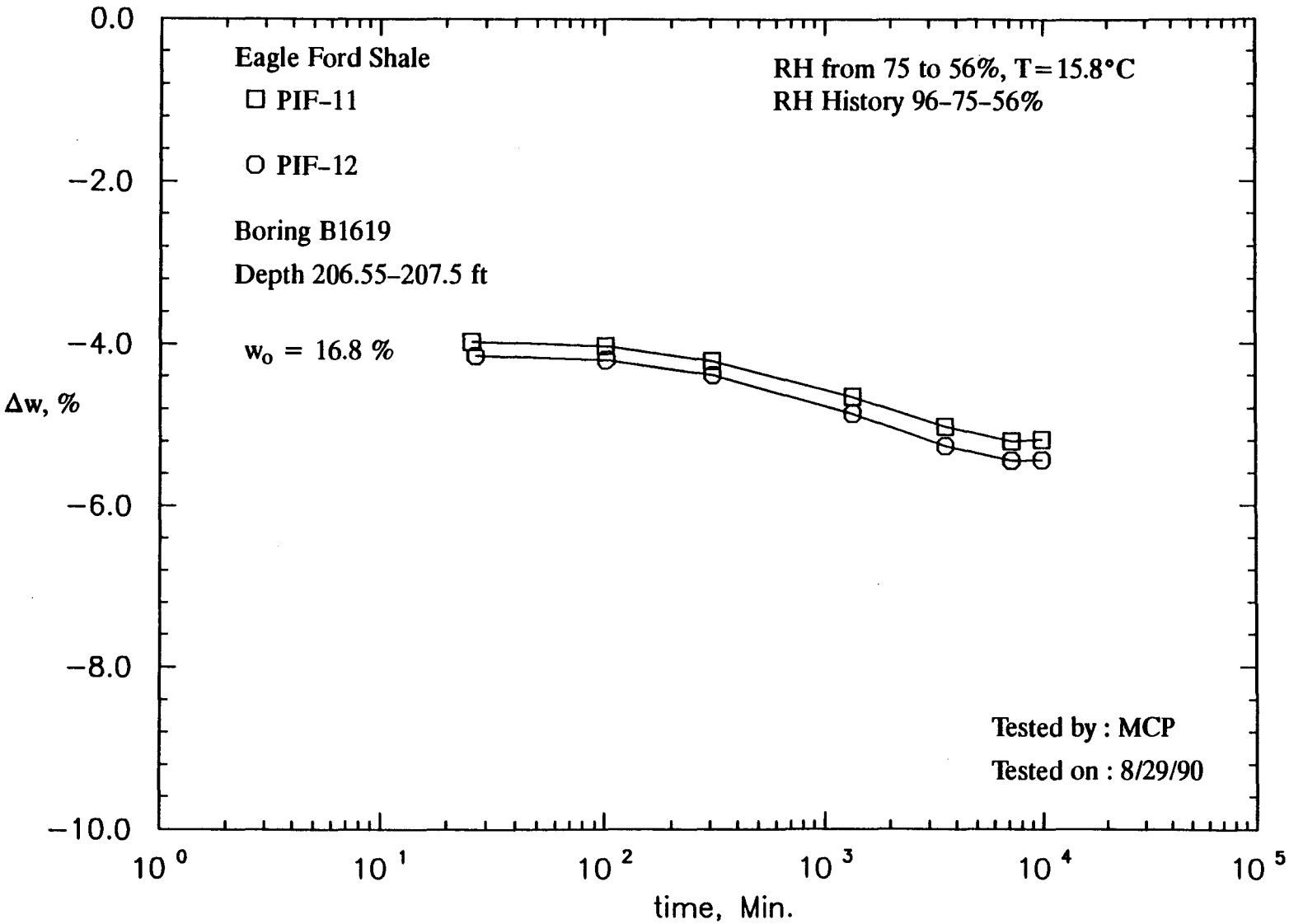


Fig. E6c Water Content Change - Log Time Relationship

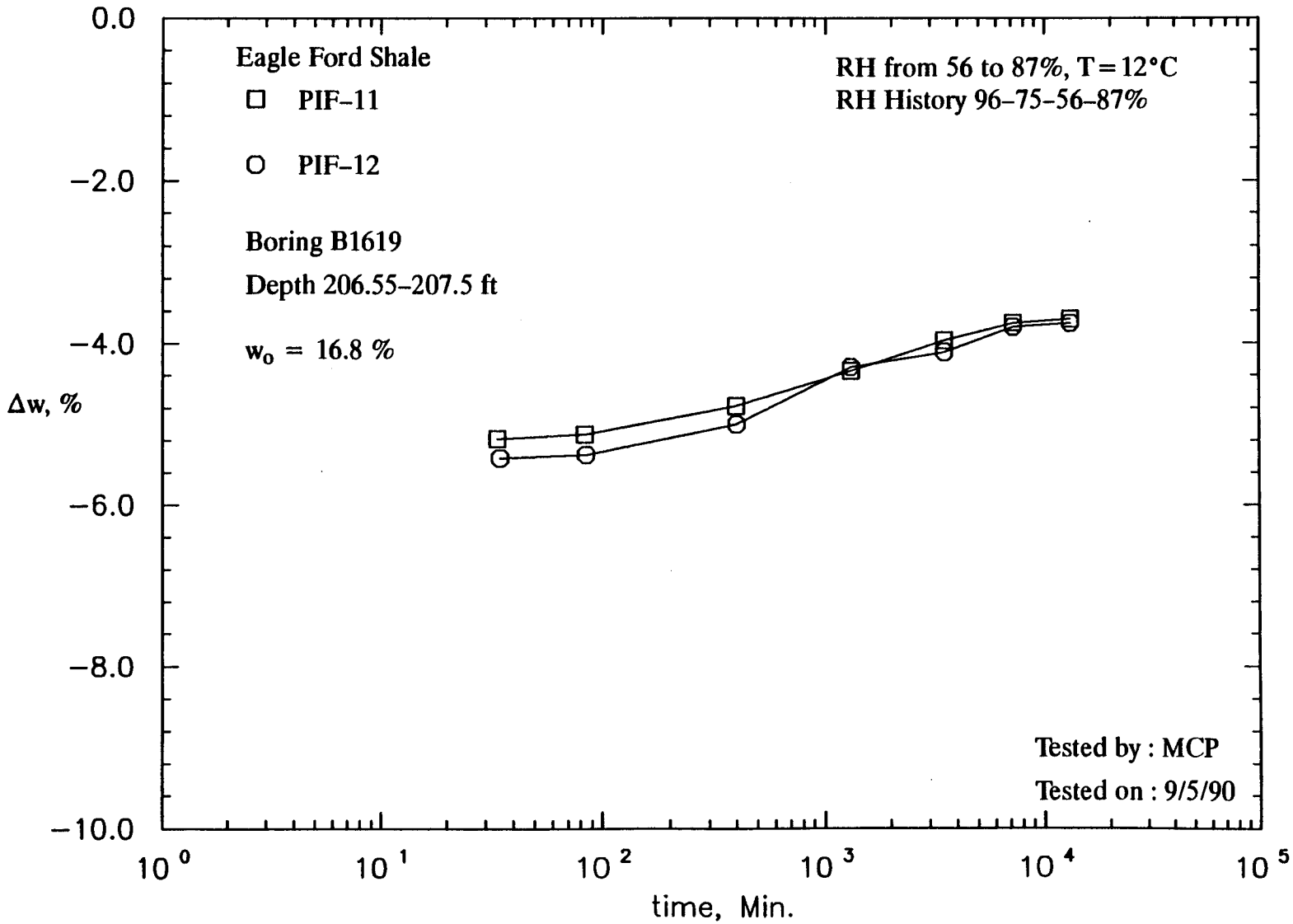


Fig. E6d Water Content Change - Log Time Relationship

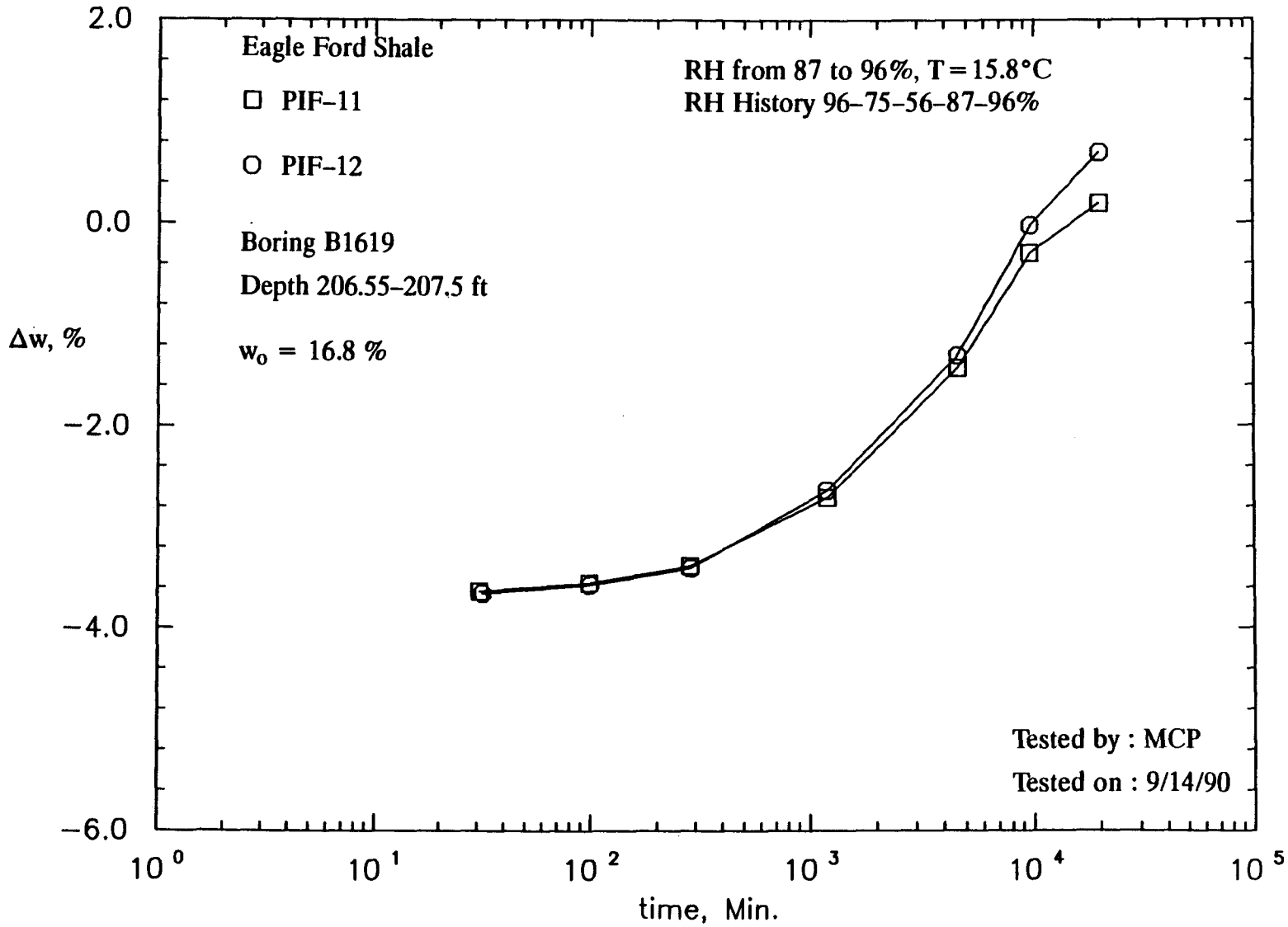


Fig. E6e Water Content Change – Log Time Relationship

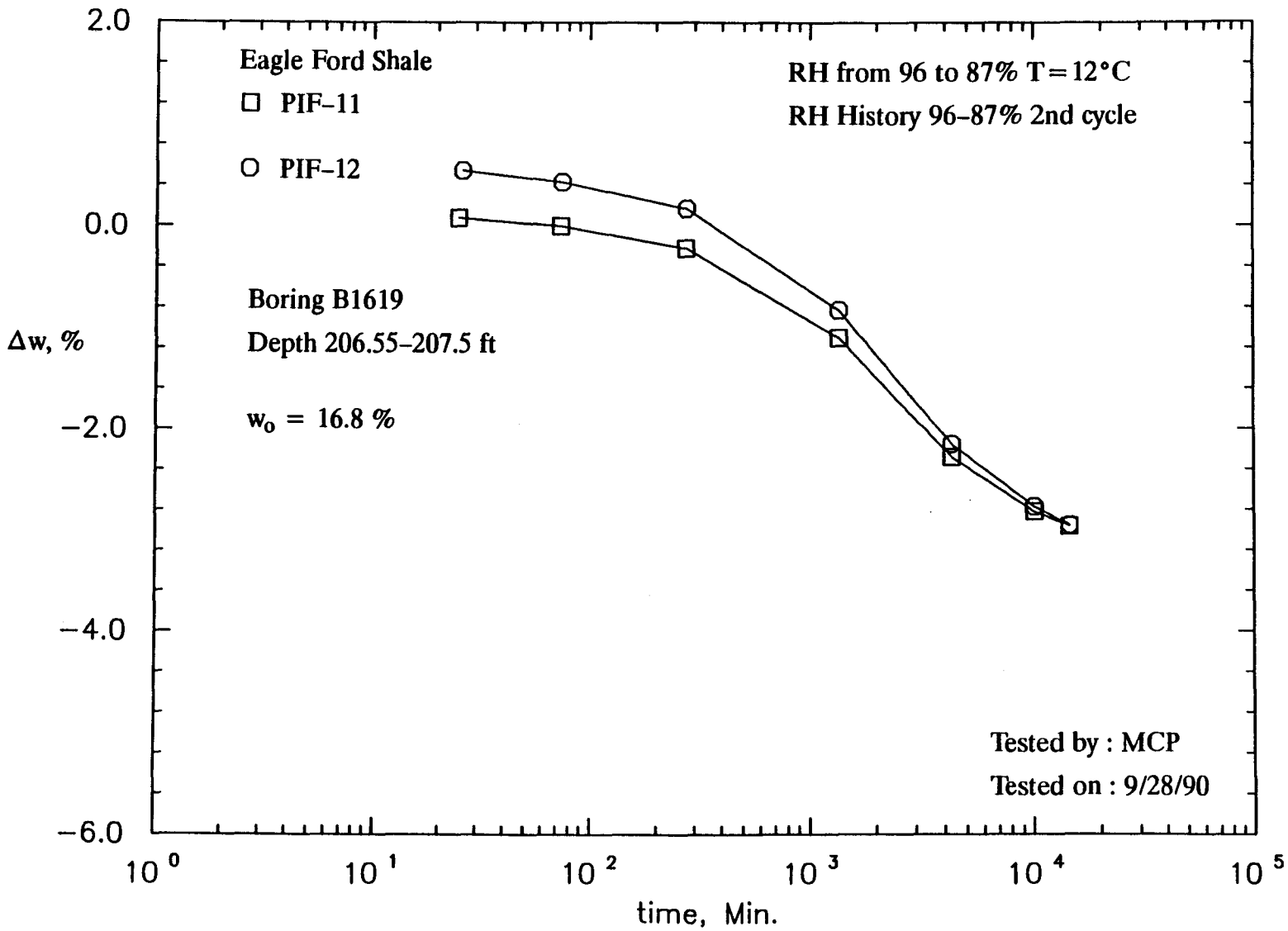


Fig. E6f Water Content Change – Log Time Relationship

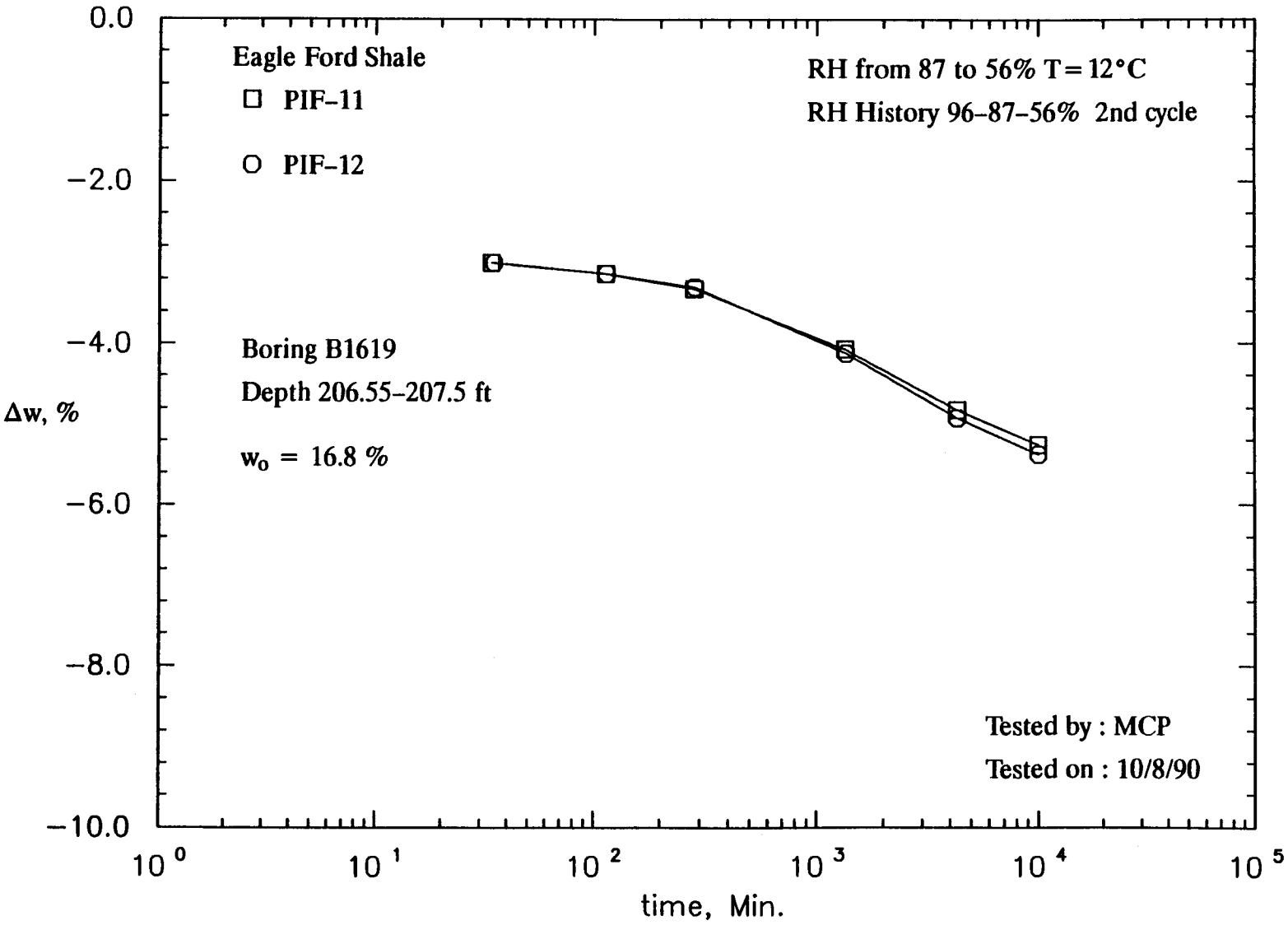


Fig. E6g Water Content Change – Log Time Relationship

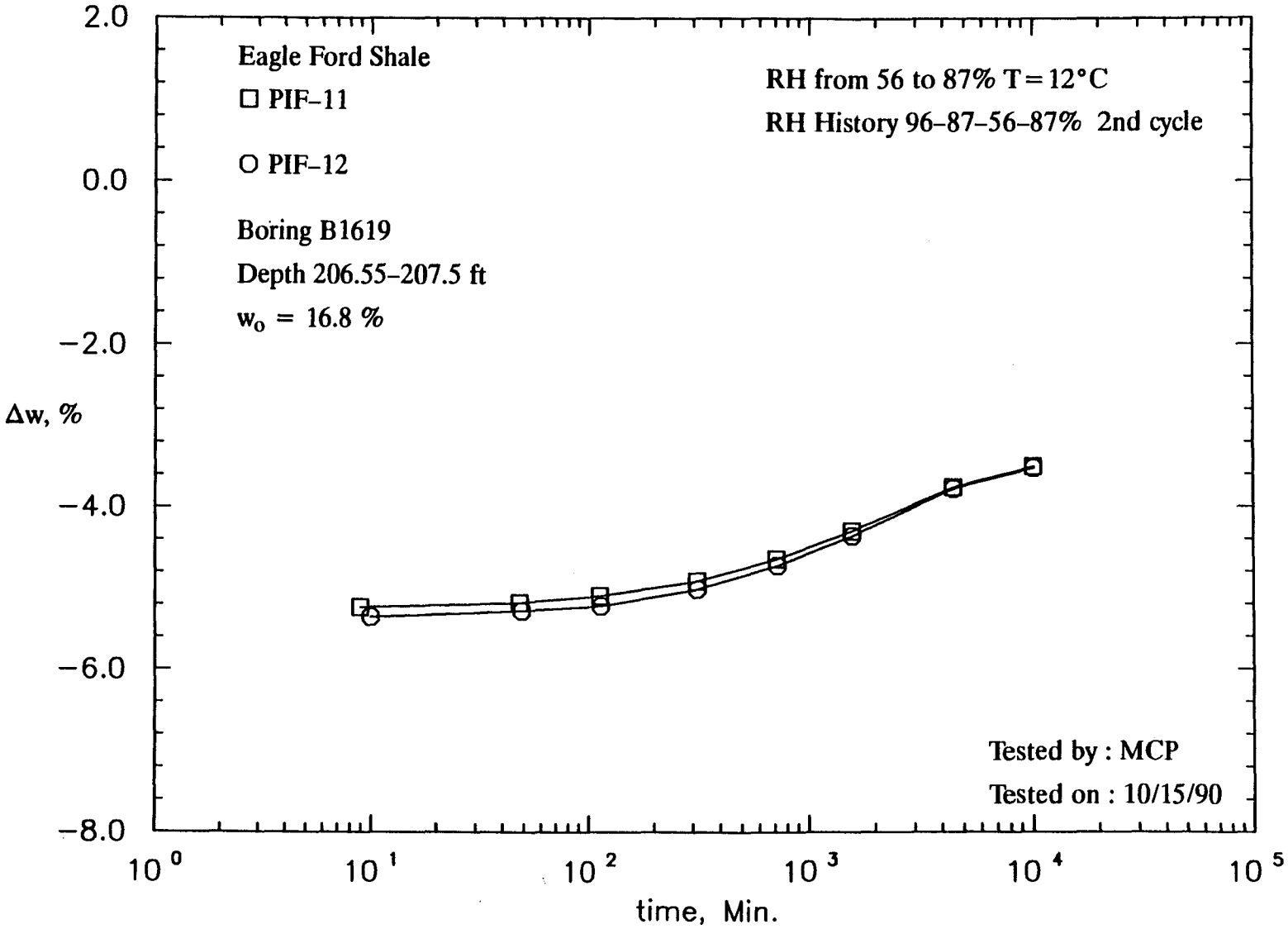


Fig. E6h Water Content Change – Log Time Relationship

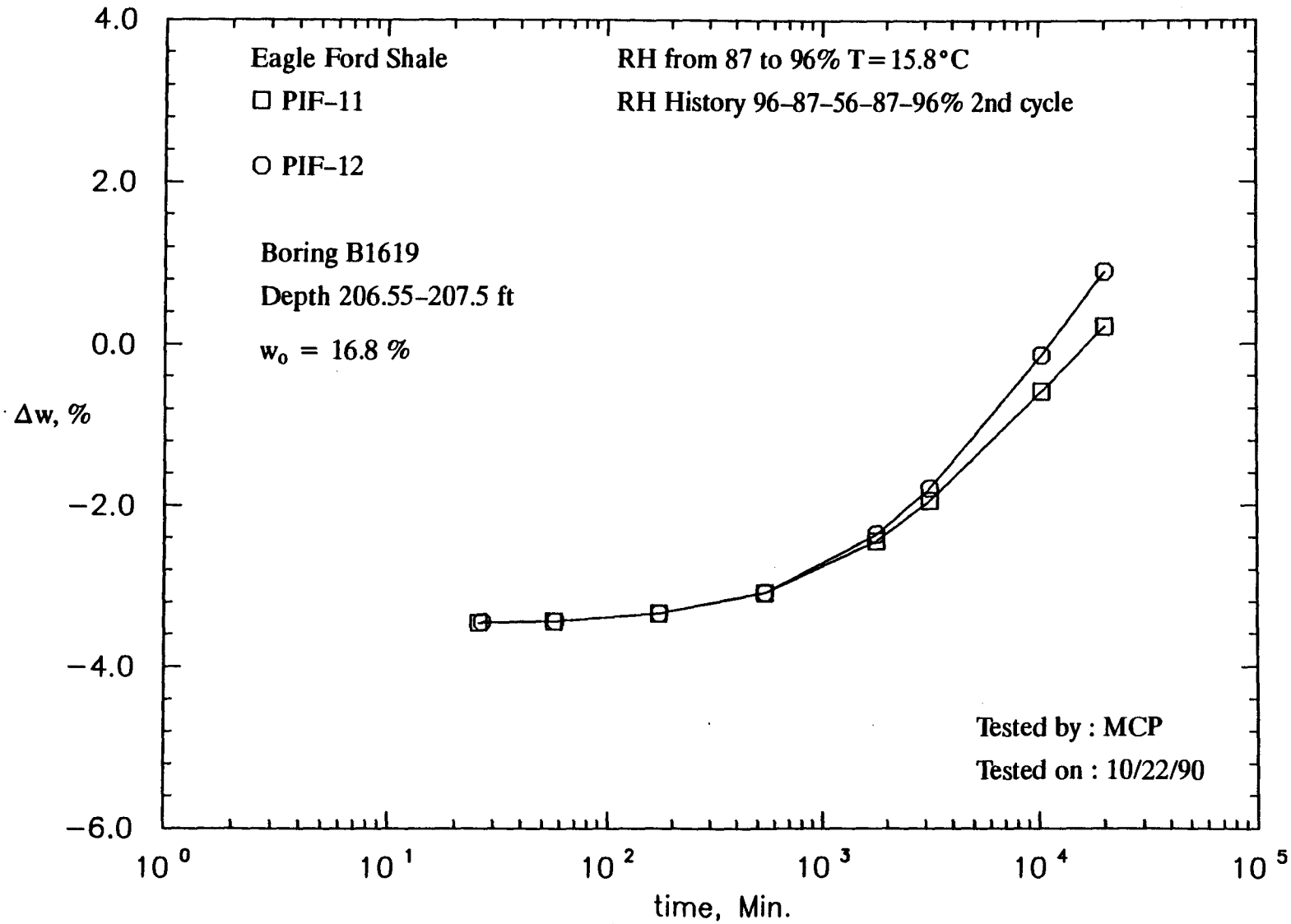


Fig. E6k Water Content Change – Log Time Relationship

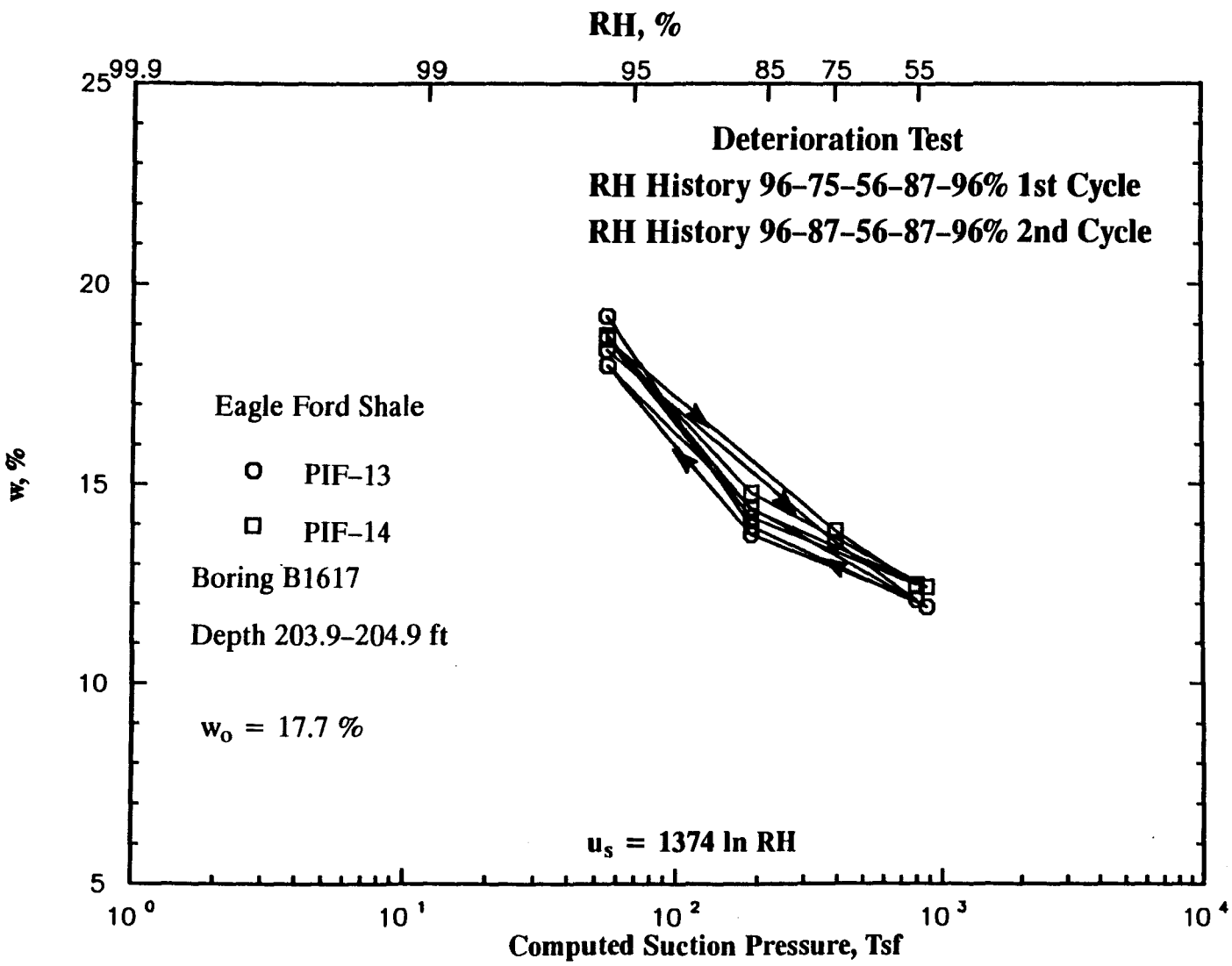


Fig. E7 Water Content - Relative Humidity Relationship

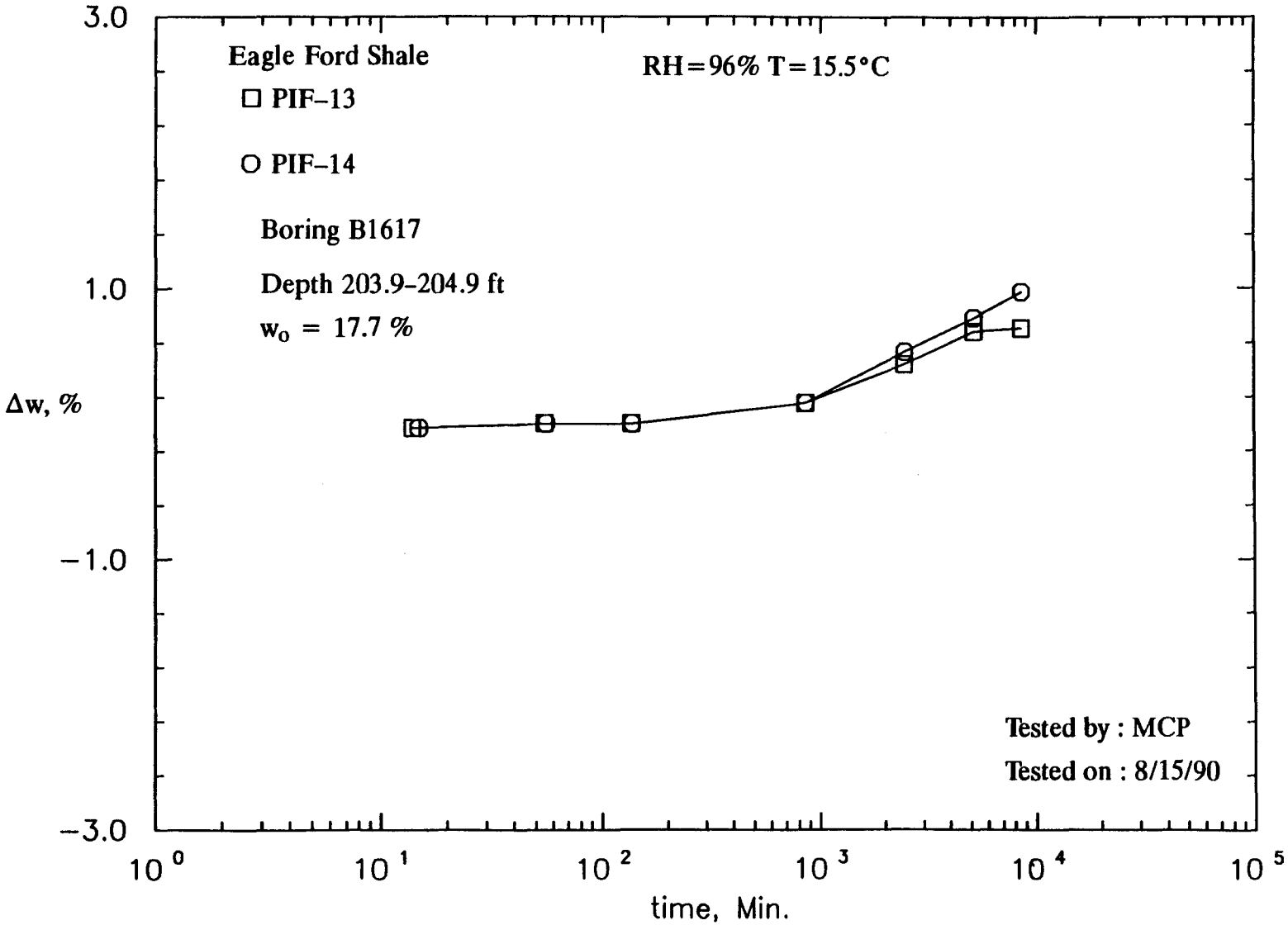


Fig. E7a Water Content Change – Log Time Relationship

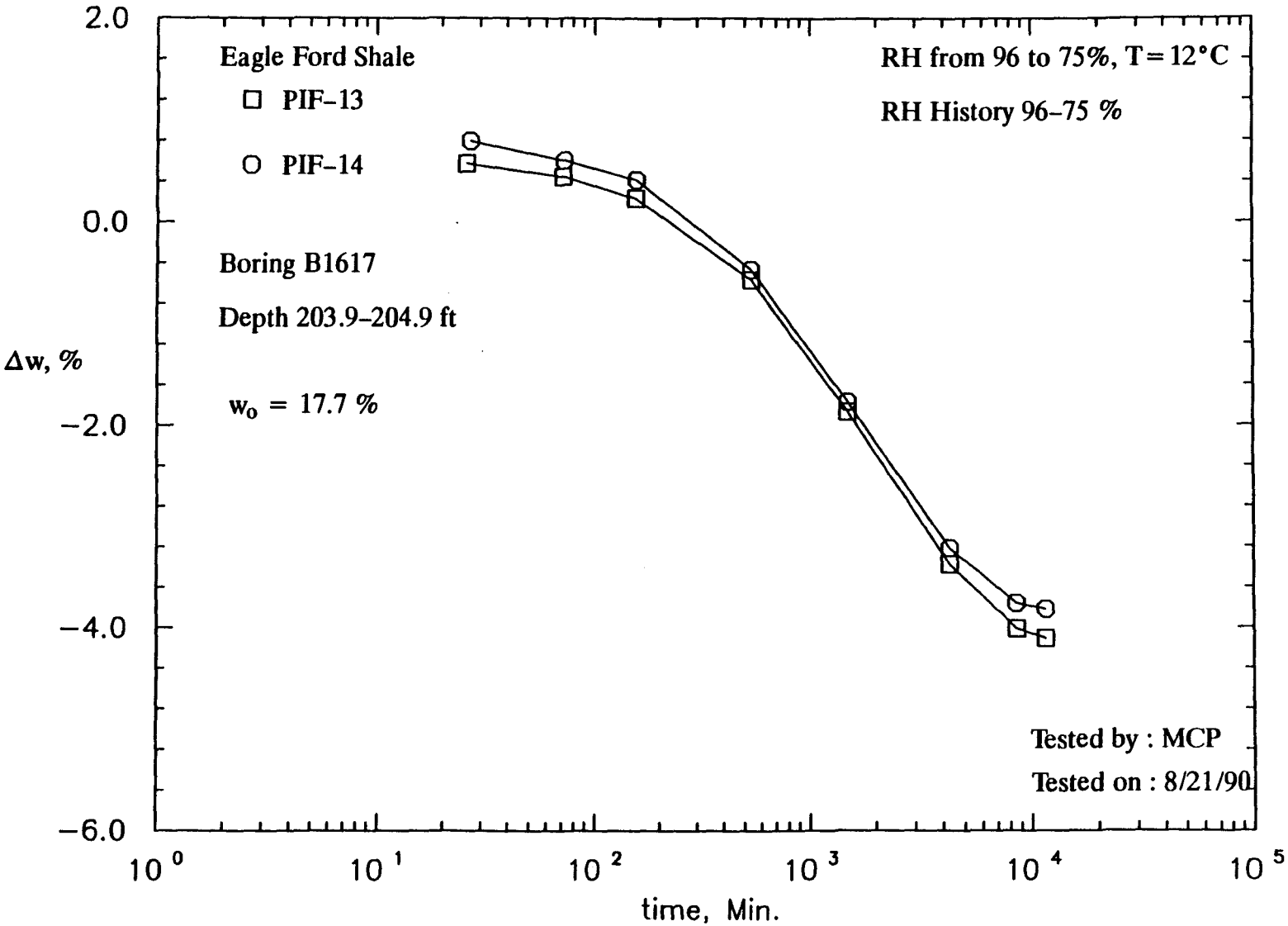


Fig. E7b Water Content Change – Log Time Relationship

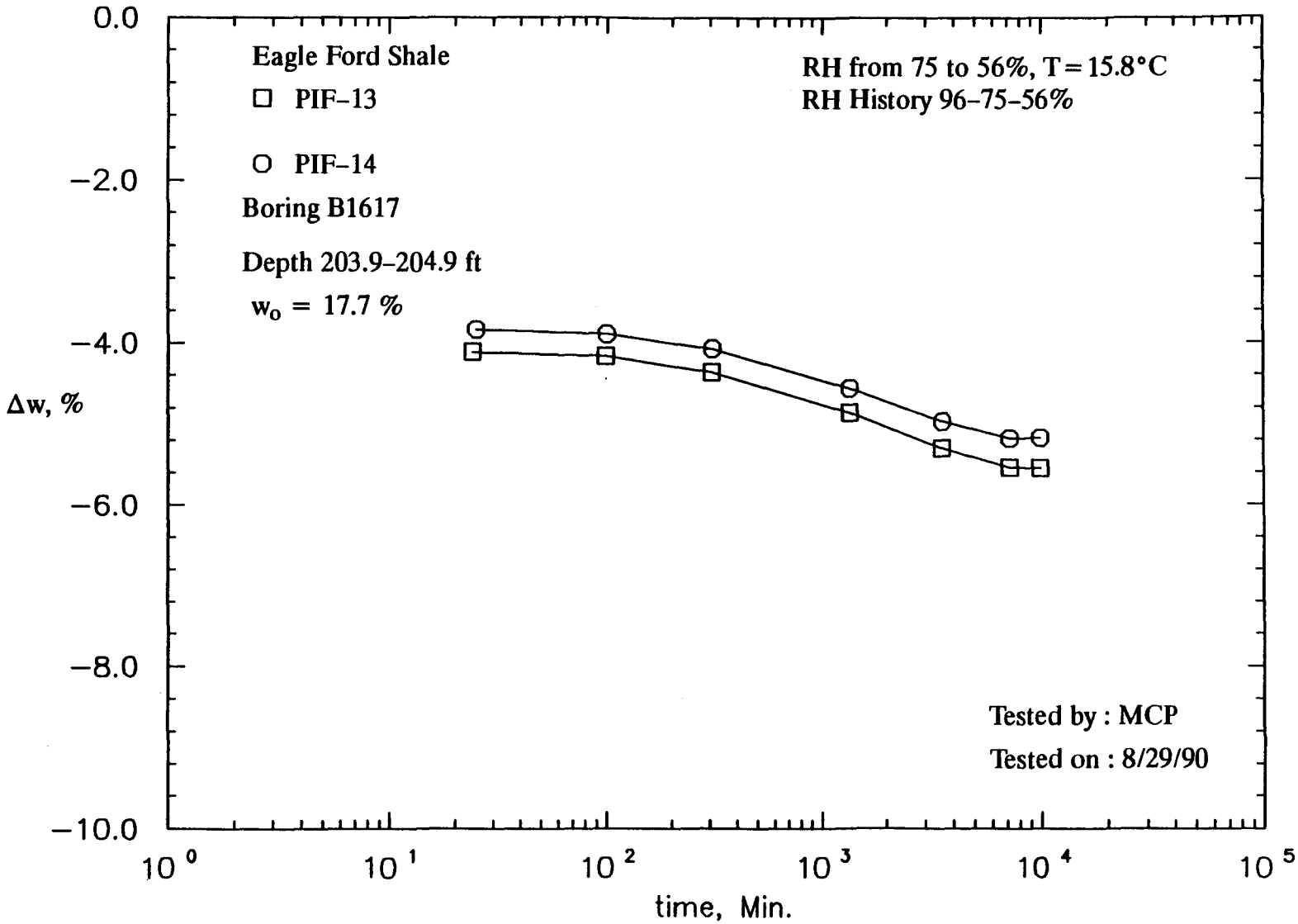


Fig. E7c Water Content Change – Log Time Relationship

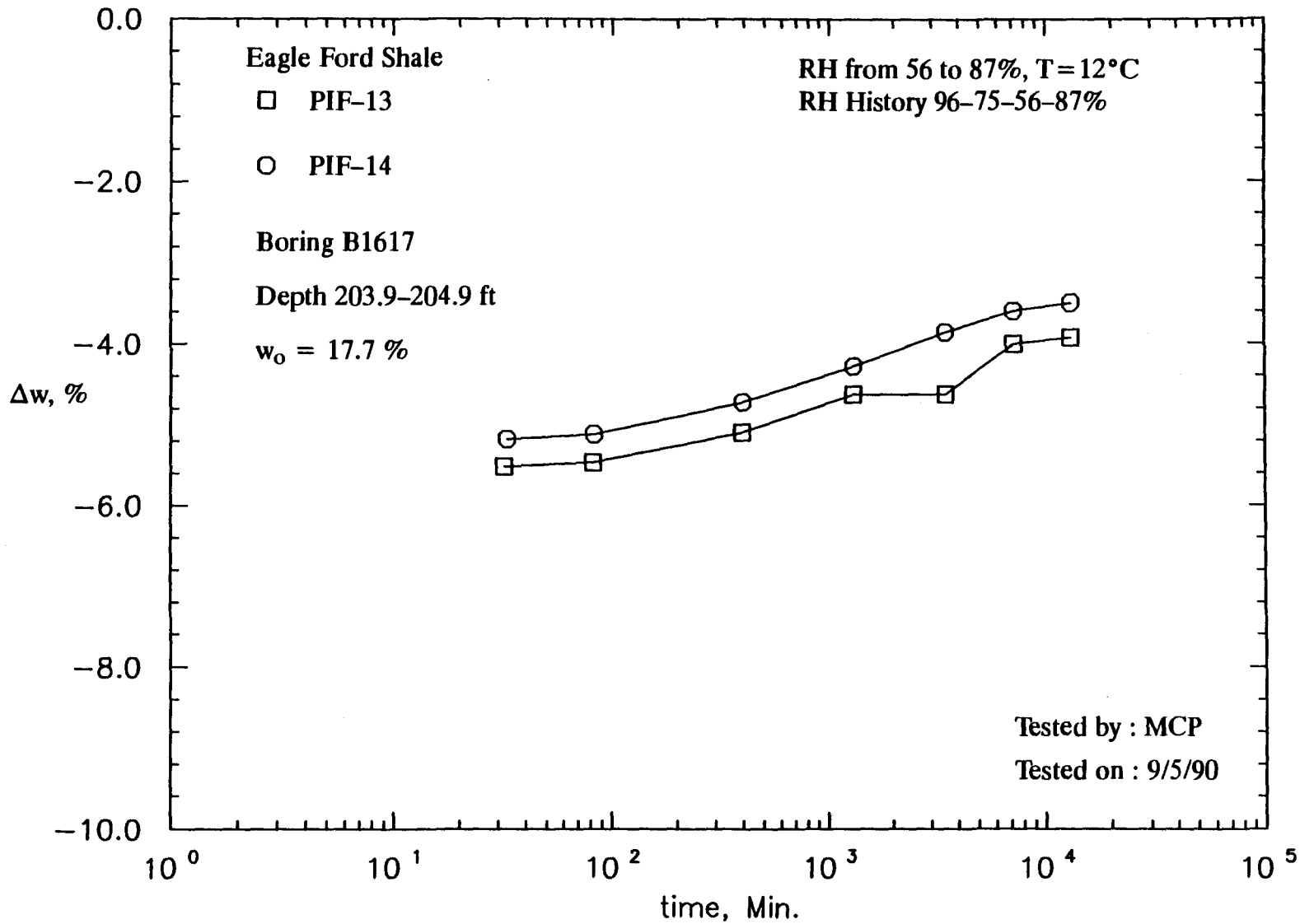


Fig. E7d Water Content Change – Log Time Relationship

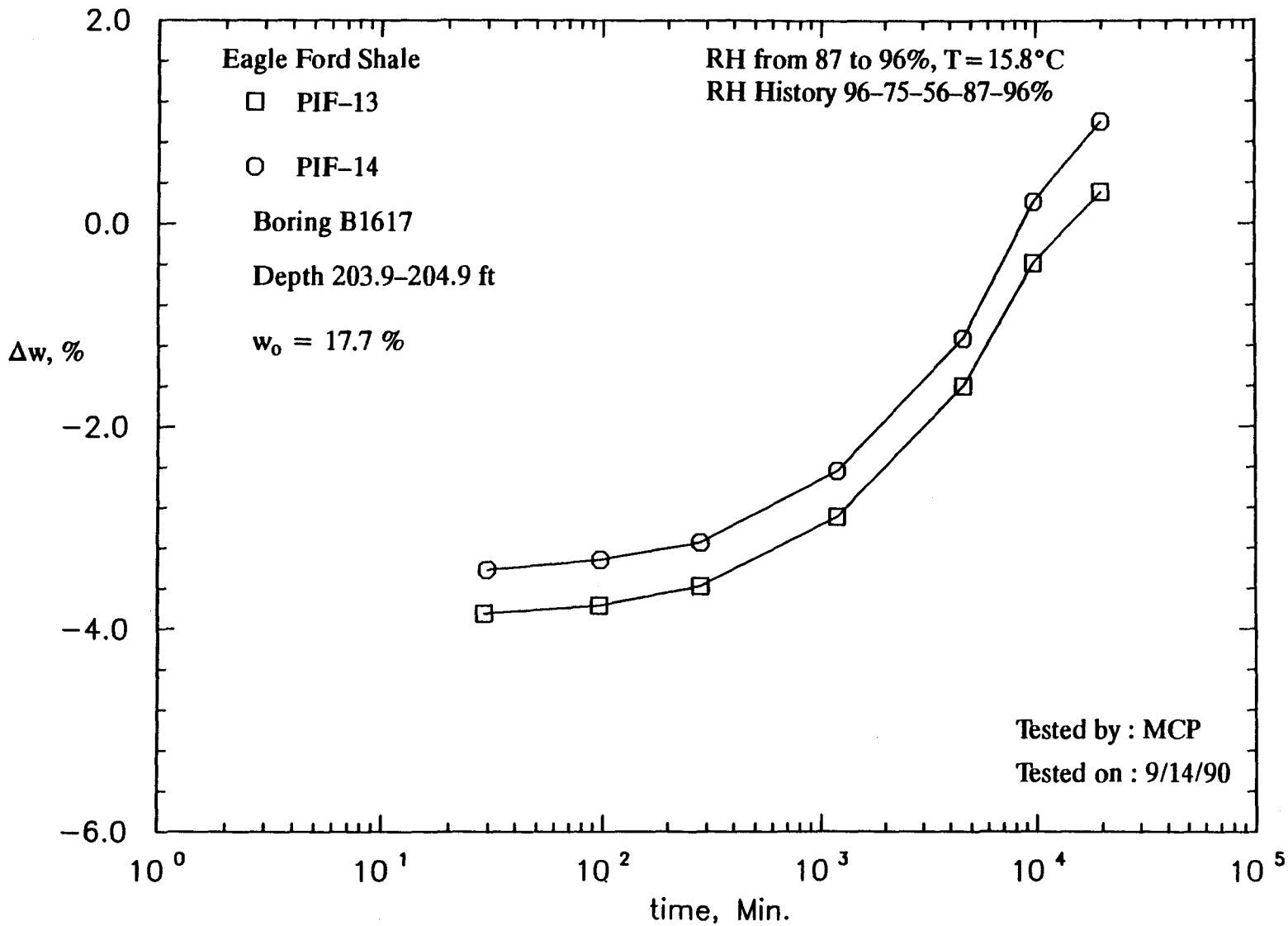


Fig. E7e Water Content Change - Log Time Relationship

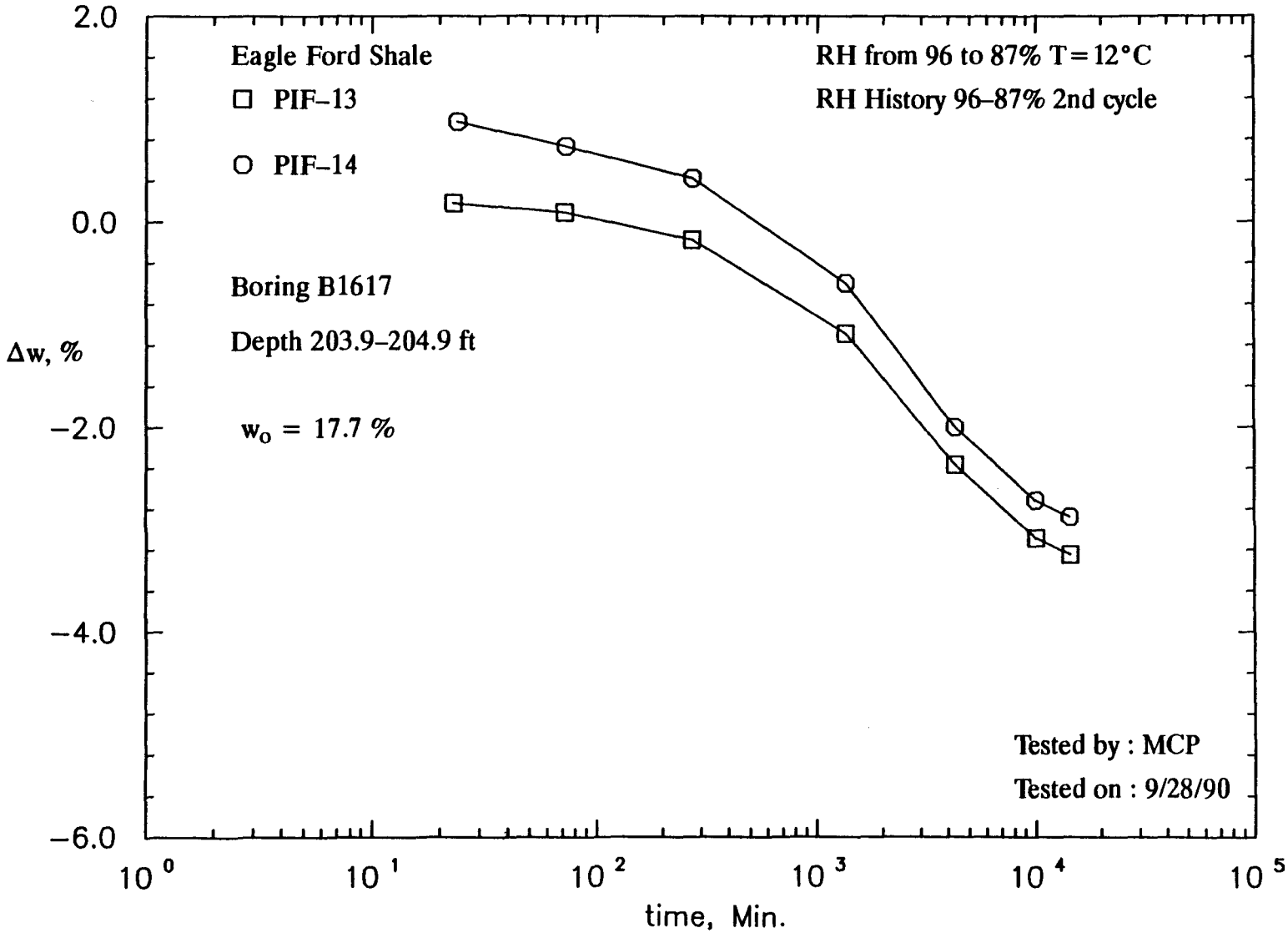


Fig. E7f Water Content Change – Log Time Relationship

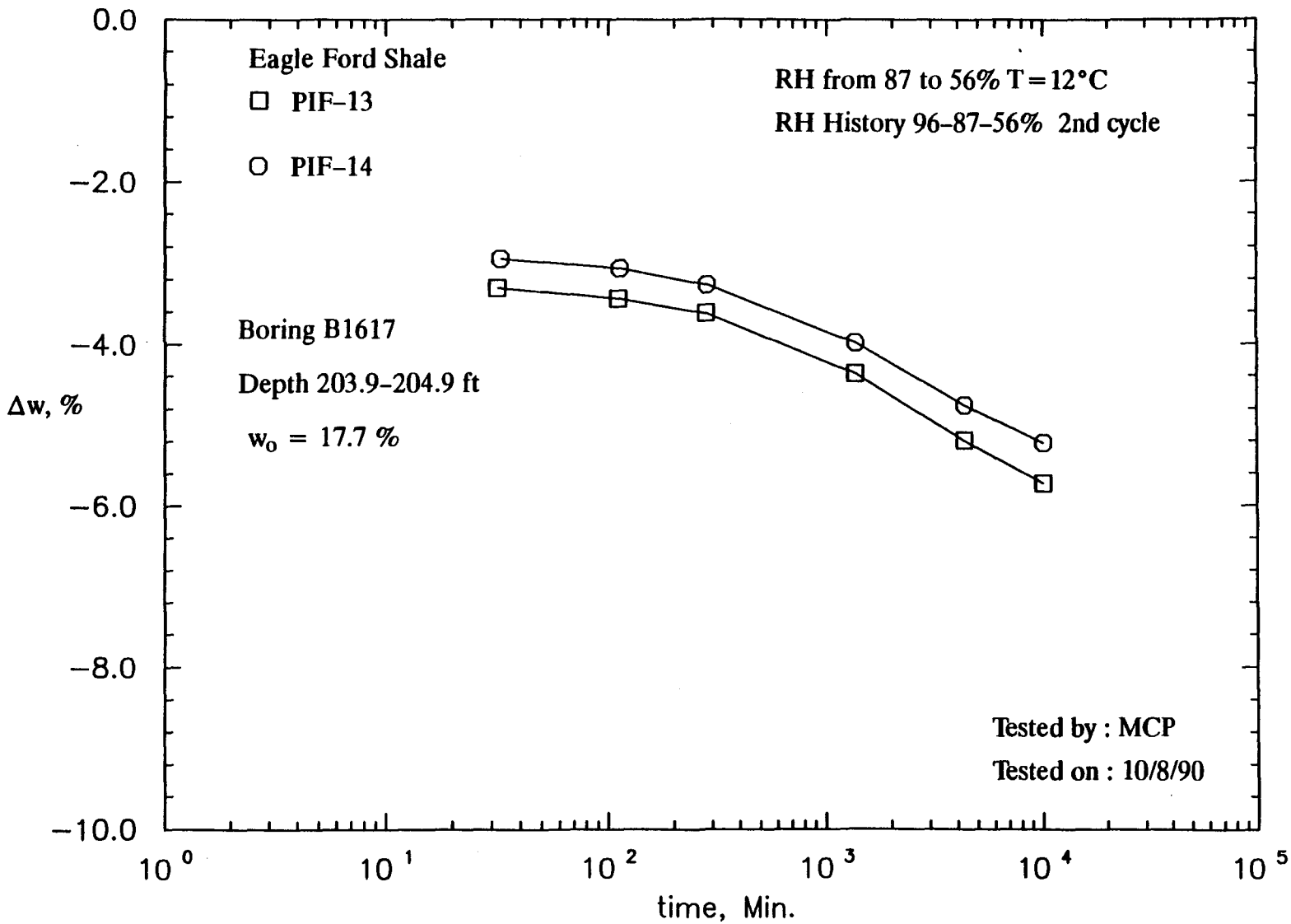


Fig. E7g Water Content Change – Log Time Relationship

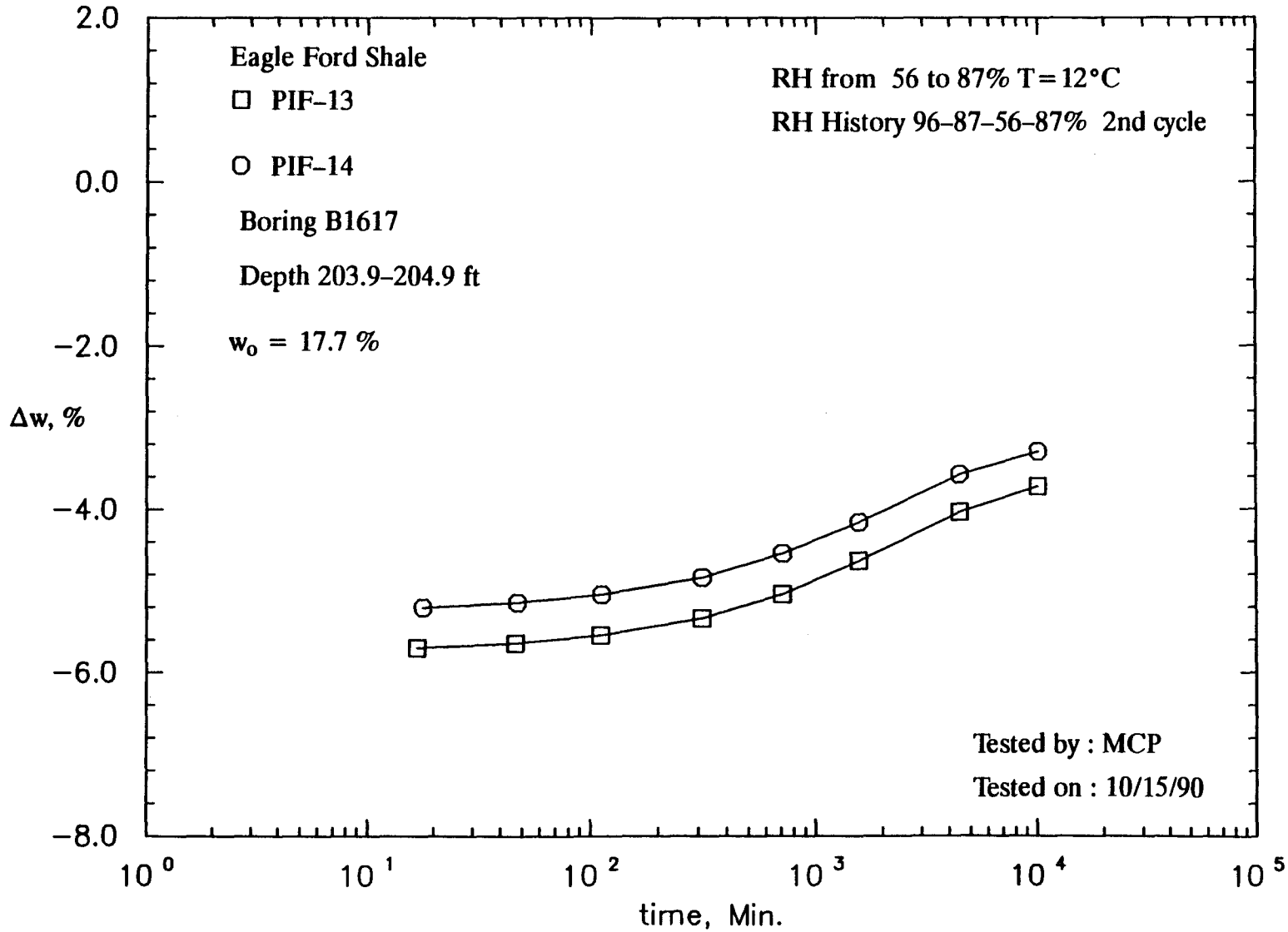


Fig. E7h Water Content Change – Log Time Relationship

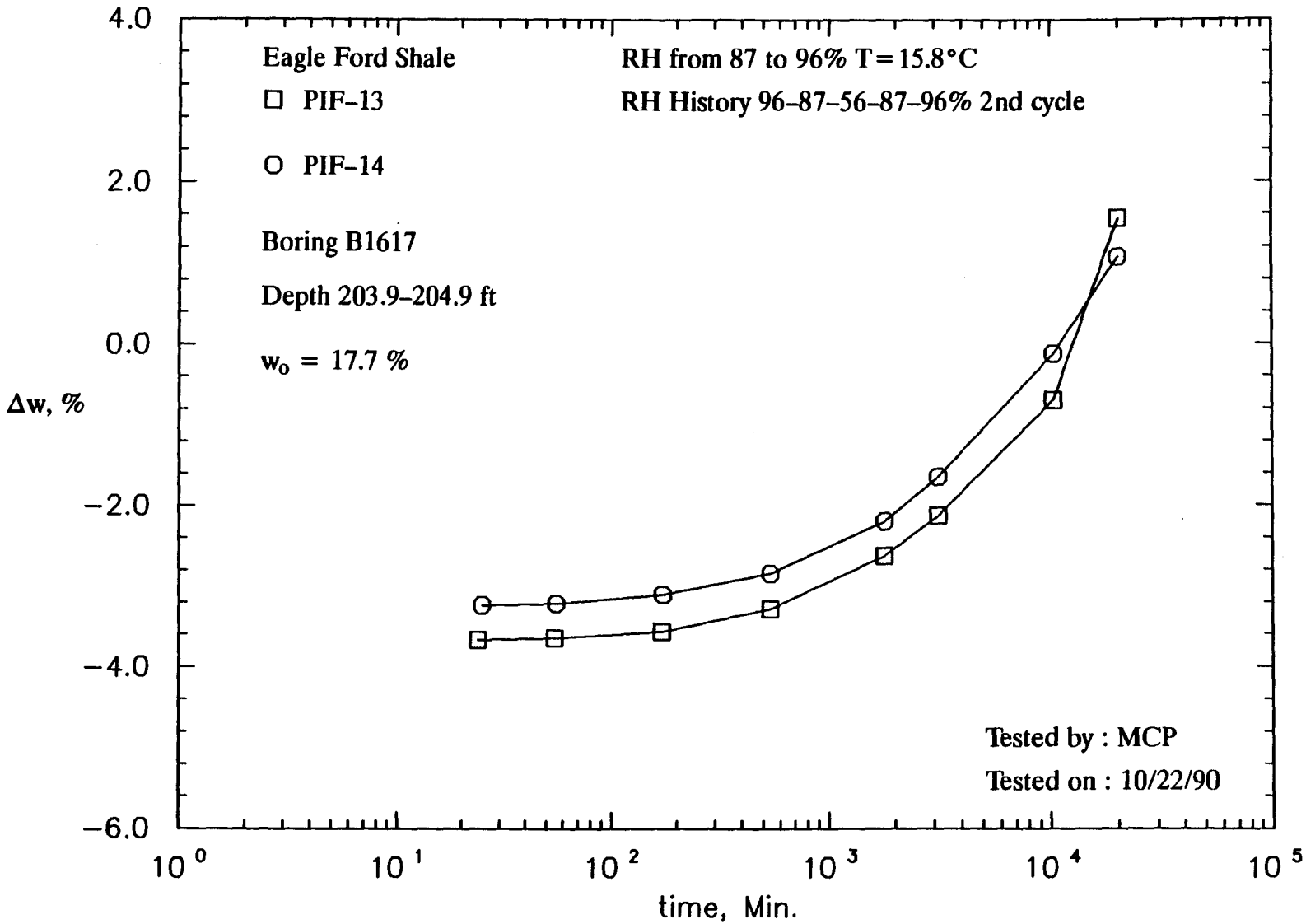


Fig. E7k Water Content Change - Log Time Relationship

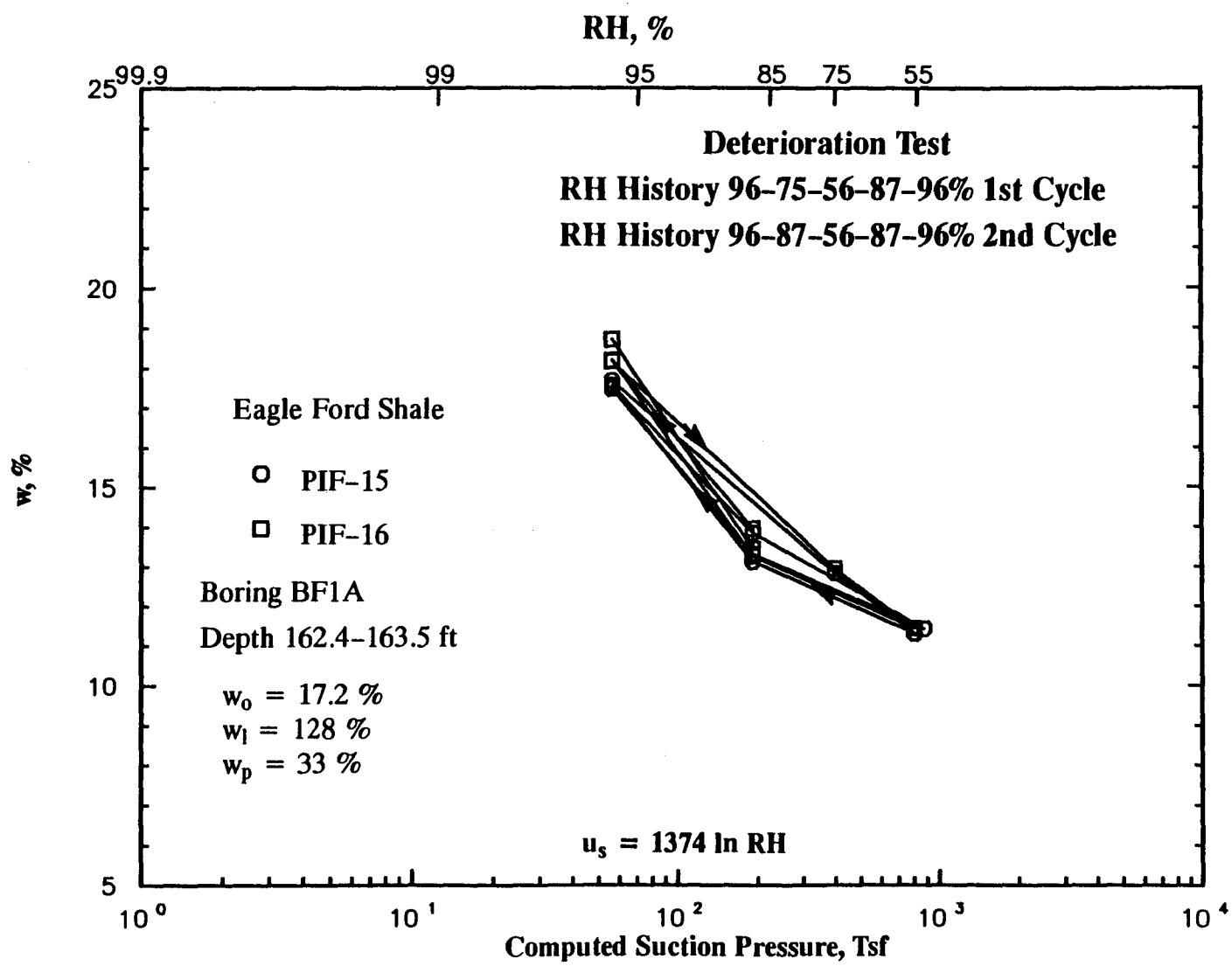


Fig. E8 Water Content - Relative Humidity Relationship

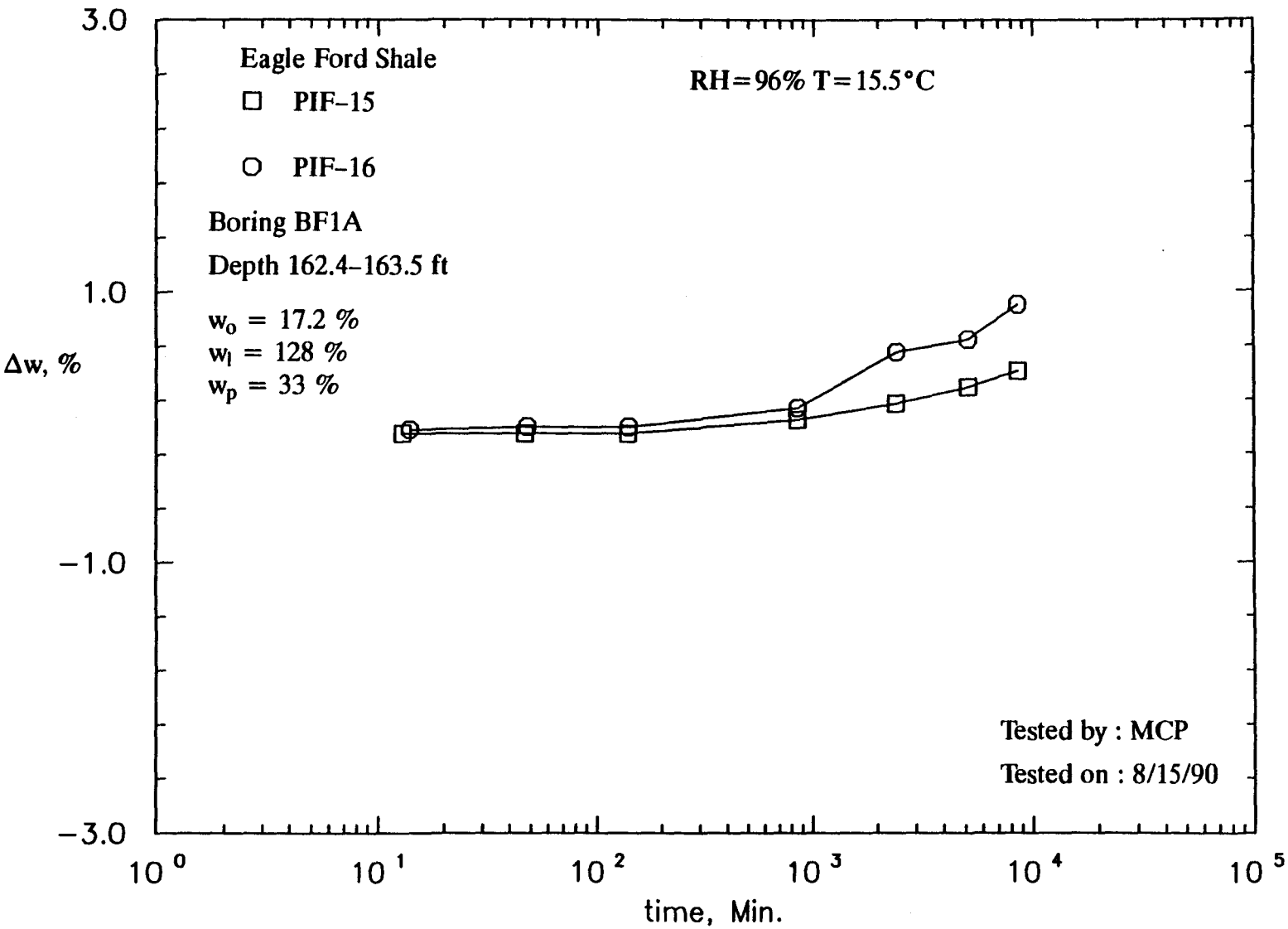


Fig. E8a Water Content Change – Log Time Relationship

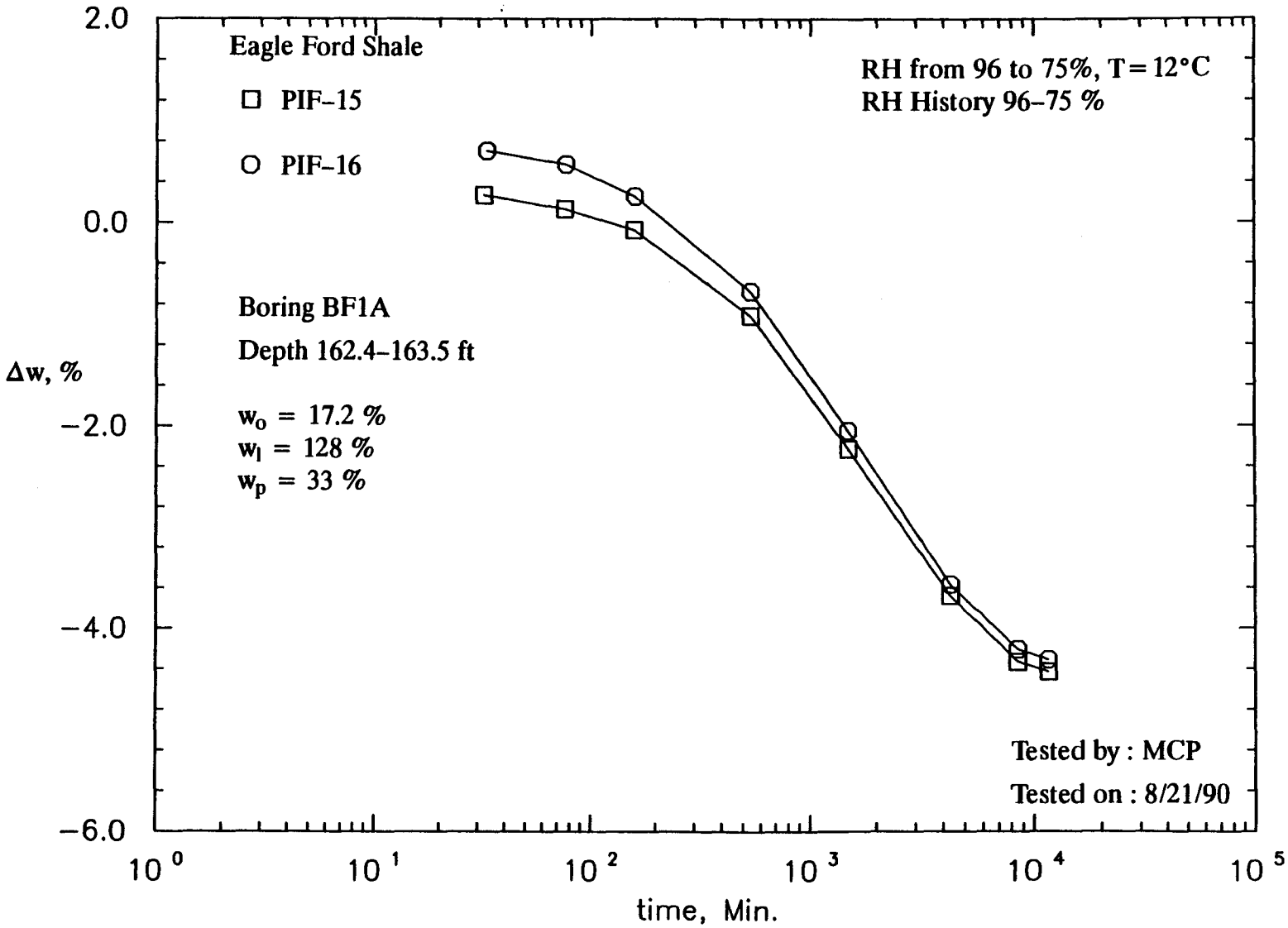


Fig. E8b Water Content Change – Log Time Relationship

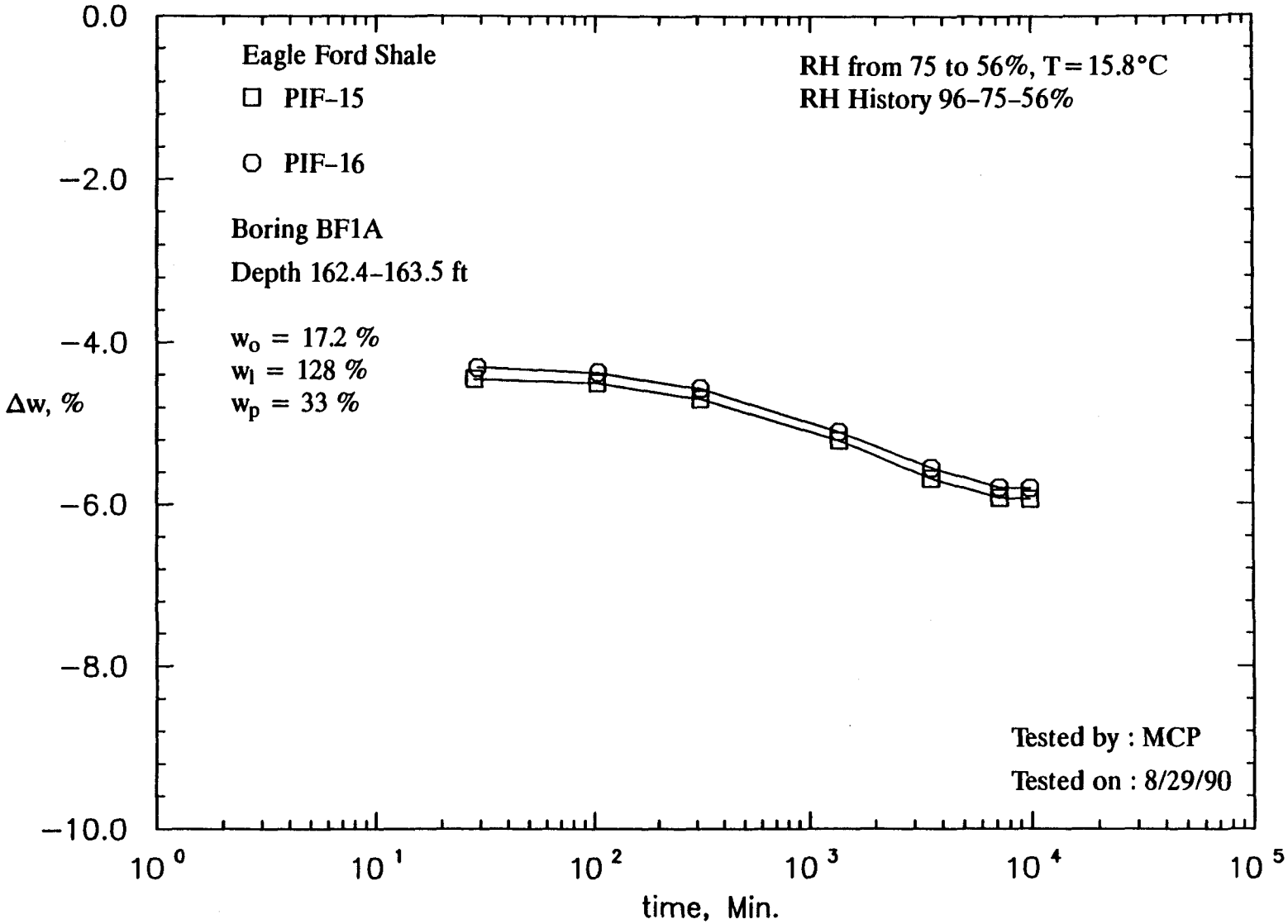


Fig. E8c Water Content Change - Log Time Relationship

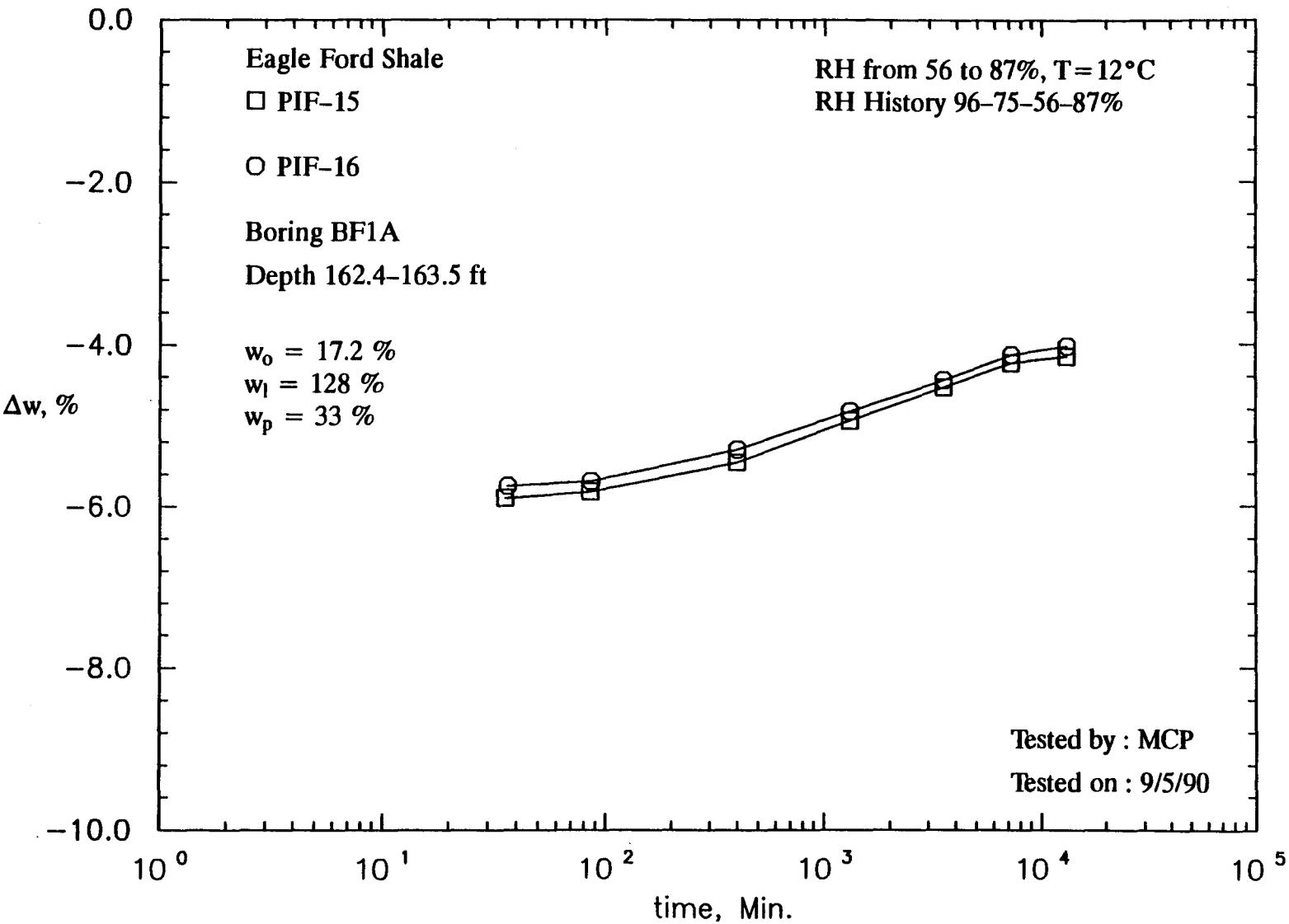


Fig. E8d Water Content Change – Log Time Relationship

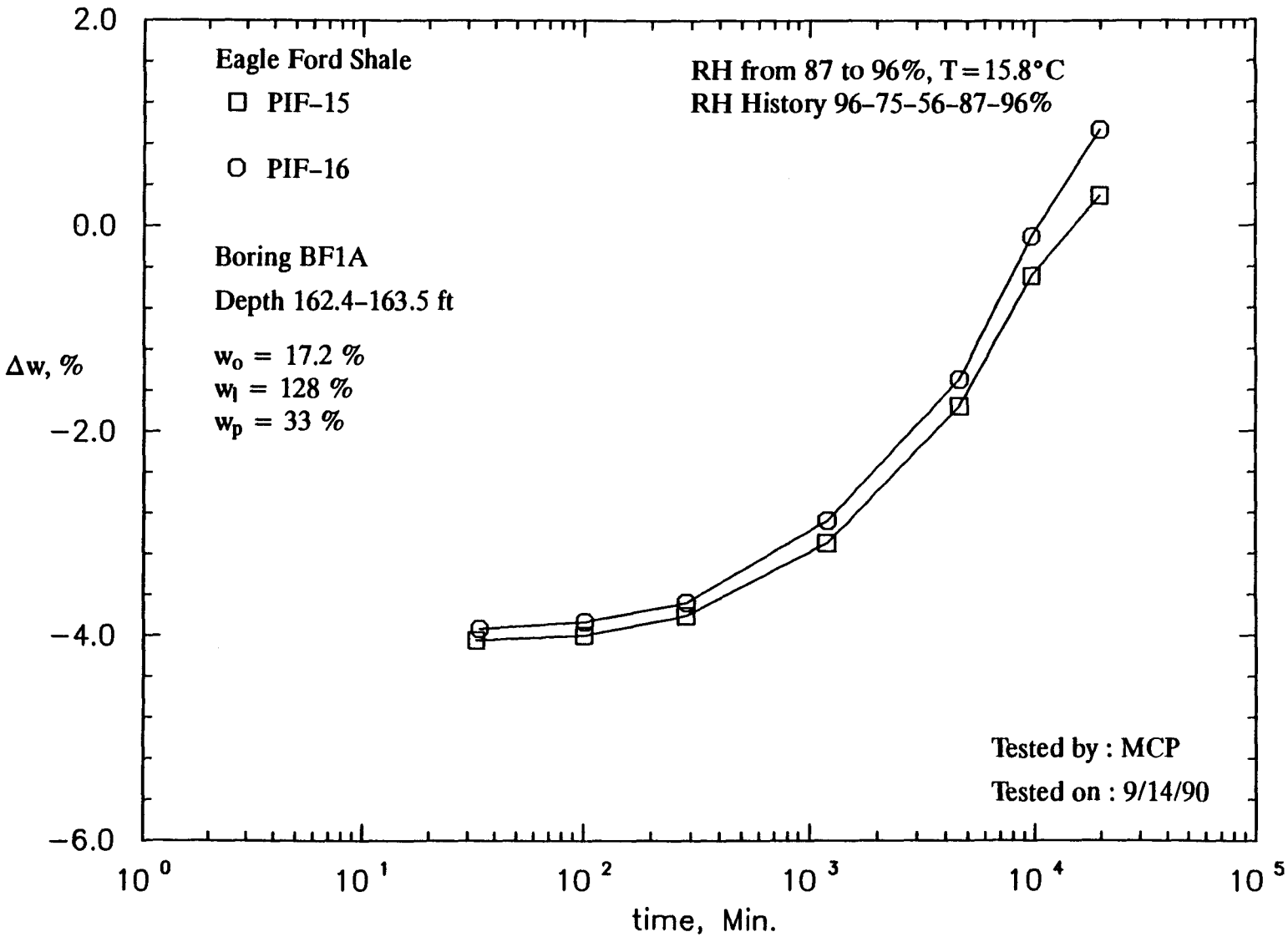


Fig. E8e Water Content Change – Log Time Relationship

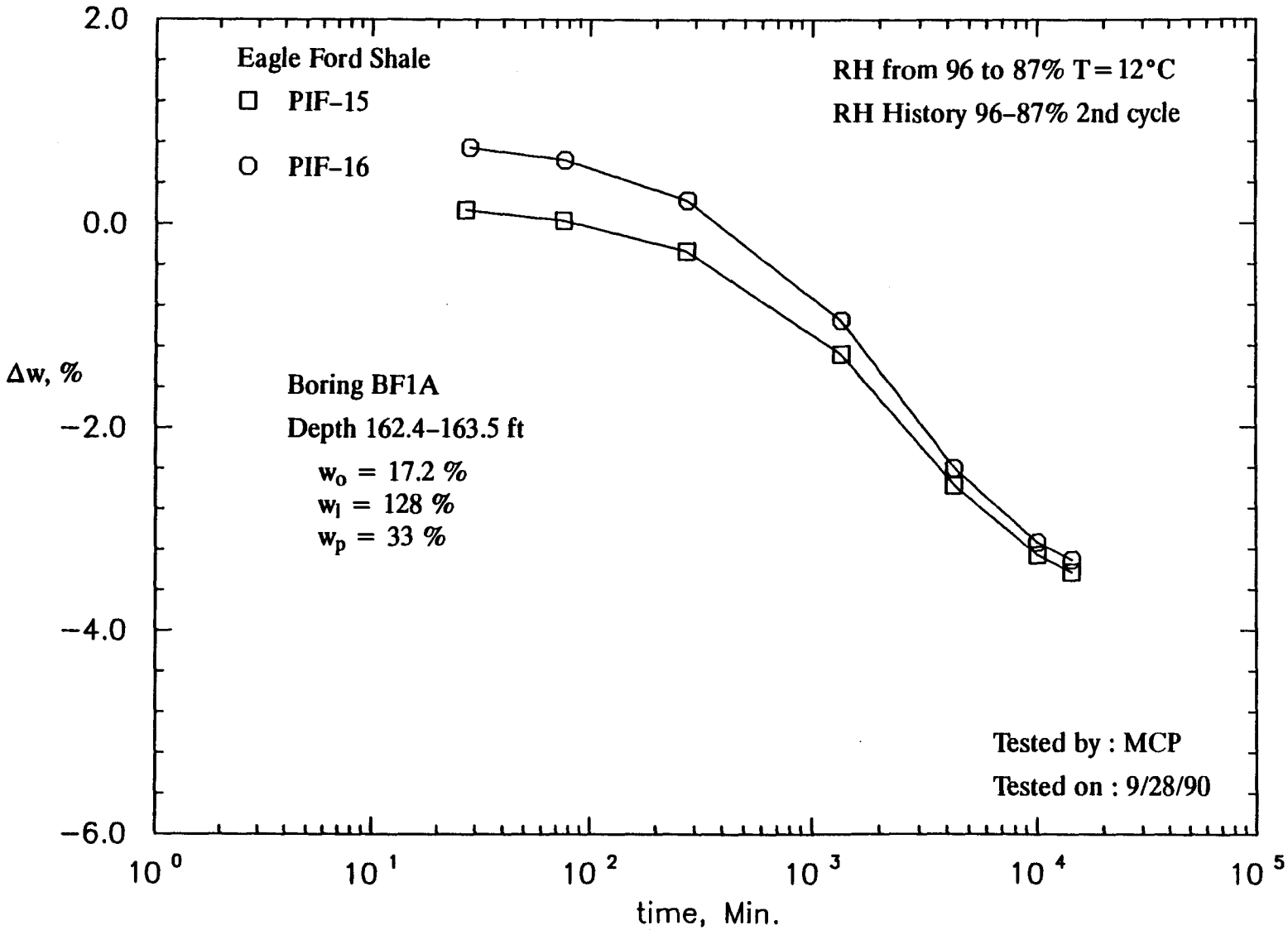


Fig. E8f Water Content Change - Log Time Relationship

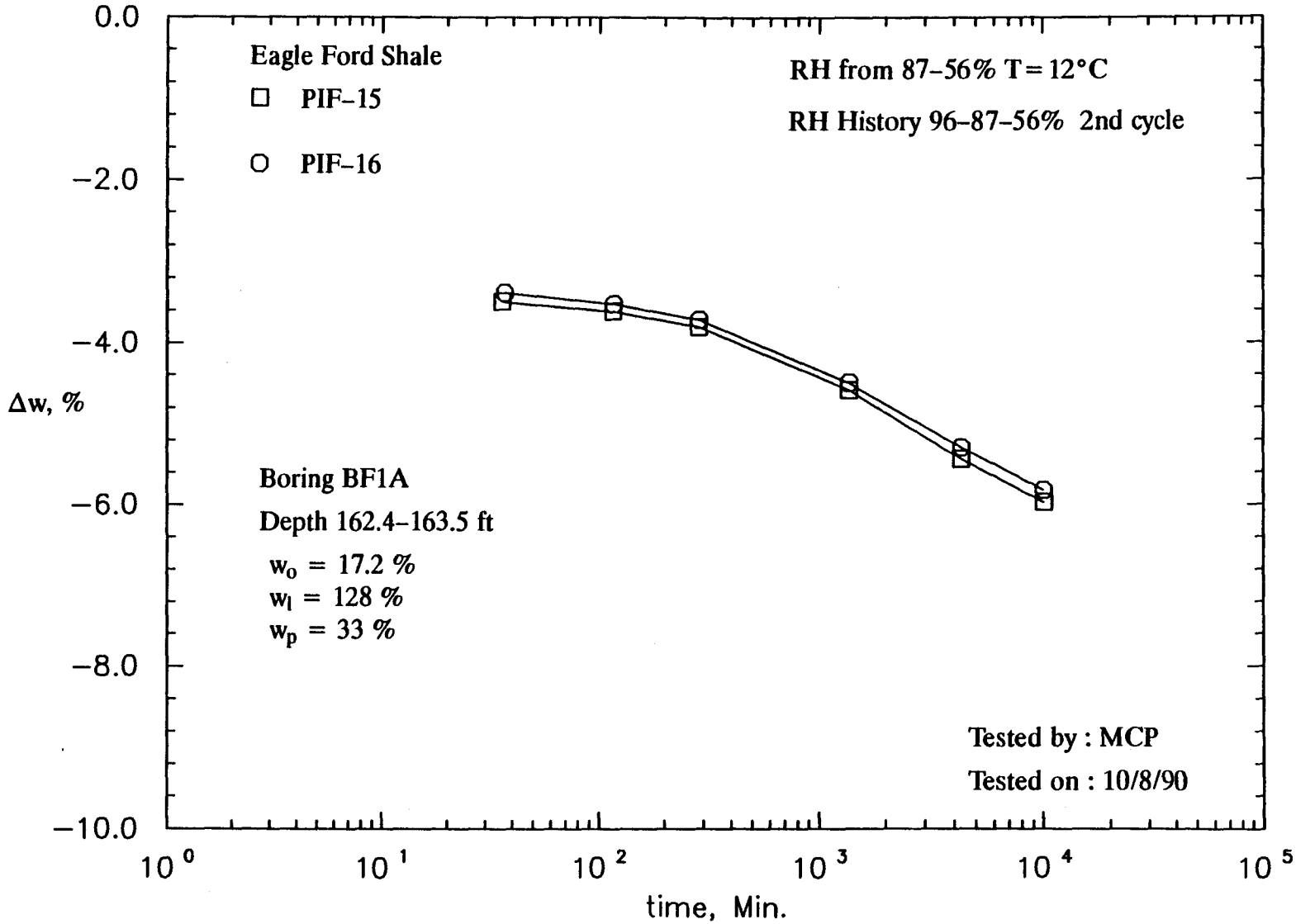


Fig. E8g Water Content Change - Log Time Relationship

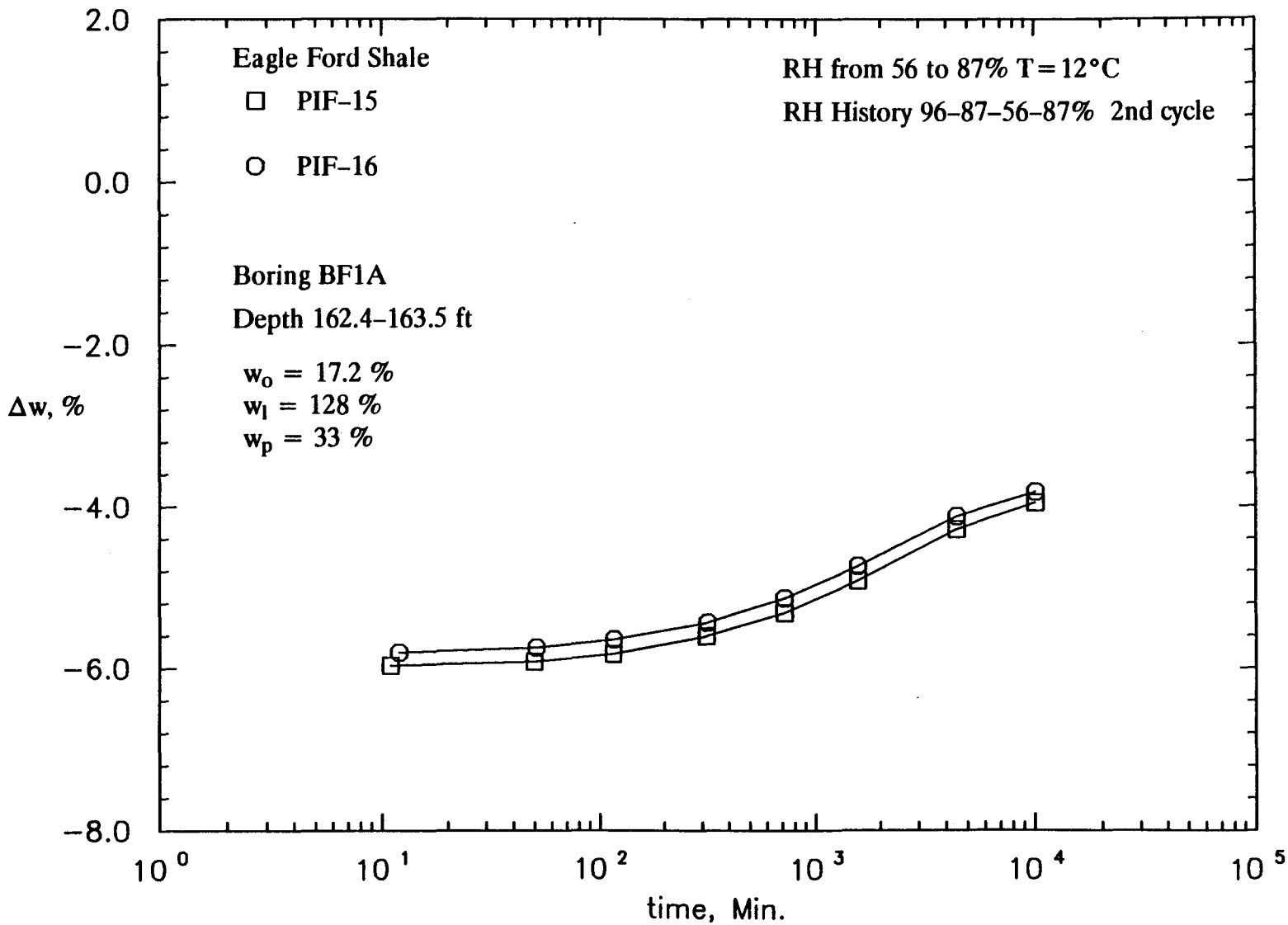


Fig. E8h Water Content Change – Log Time Relationship

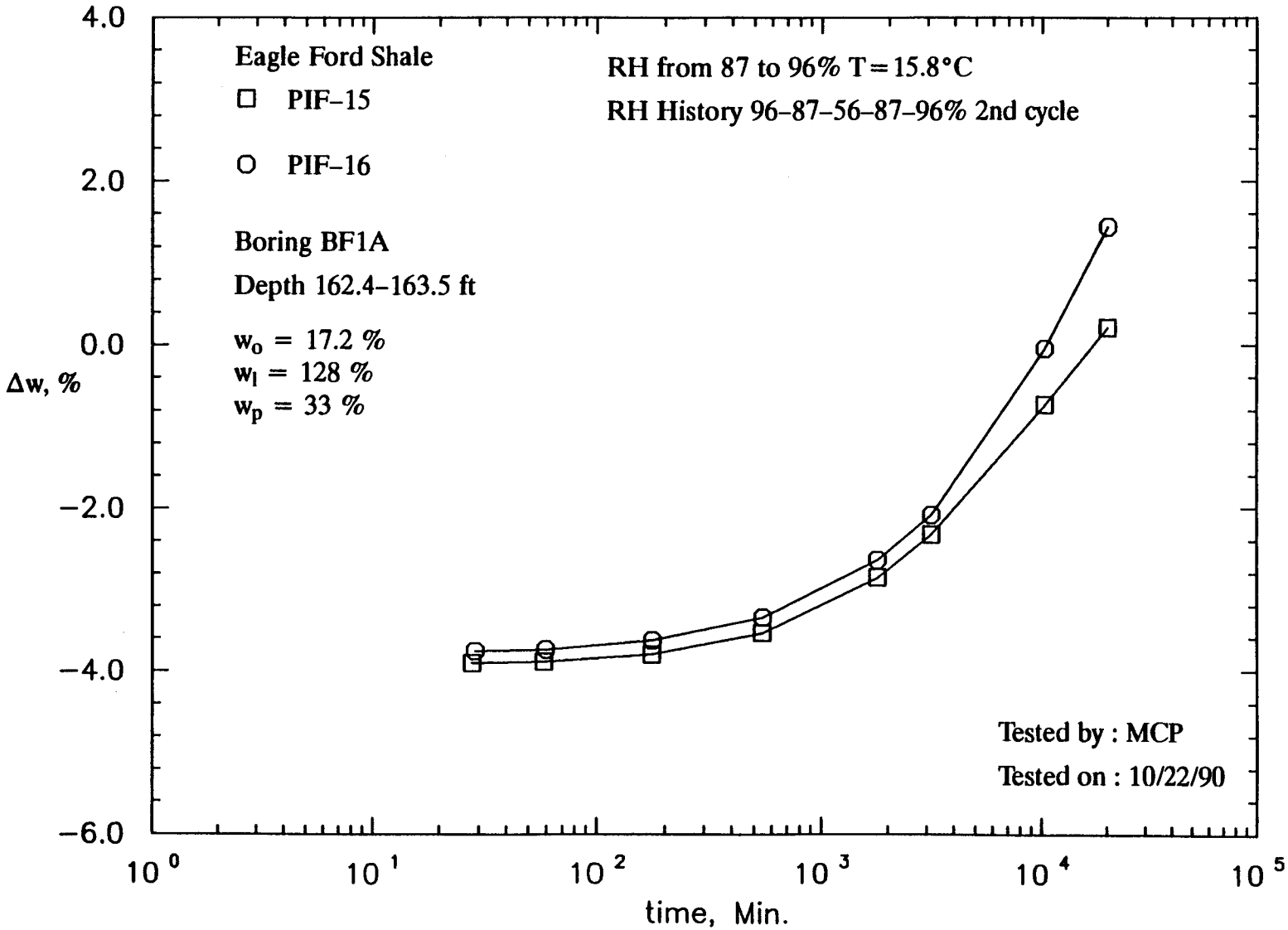


Fig. E8k Water Content Change – Log Time Relationship