DEVELOPMENT
OF A
RATIONAL CHARACTERIZATION METHOD
FOR
IOWA FLY ASH

ANNUAL PROGRESS REPORT 2
NOVEMBER 30, 1987

IOWA DOT PROJECT HR-286
ERI PROJECT 1847

Sponsored by the Highway Division of the
Iowa Department of Transportation and the
Iowa Highway Research Board.

ENGINEERING RESEARCH INSTITUTE
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OF A
RATIONAL CHARACTERIZATION METHOD
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ANNUAL PROGRESS REPORT 2
DECEMBER 1, 1987

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INTRODUCTION

The following report summarizes research activities on the project for the period December 1, 1986 to November 30, 1987. Research efforts for the second year deviated slightly from those described in the project proposal. By the end of the second year of testing, it was possible to begin evaluating how power plant operating conditions influenced the chemical and physical properties of fly ash obtained from one of the monitored power plants (Ottumwa Generating Station, OGS). Hence, several of the tasks initially assigned to the third year of the project (specifically tasks D, E, and F) were initiated during the second year of the project. Manpower constraints were balanced by delaying full scale implementation of the quantitative X-ray diffraction and differential thermal analysis tasks until the beginning of the third year of the project. Such changes should have little bearing on the outcome of the overall project.

RESEARCH APPROACH

Preliminary work at the Materials Analysis and Research Laboratory (MARL) had indicated that the physical properties of Class C fly ash pastes changed significantly as a function of time [1]. Mortar cube data at the Iowa Department of Transportation (IDOT, test method 212), also indicated significant variations in physical properties of Class C fly ashes. Hence, a testing program was initiated to monitor the physical and chemical characteristics of the major Class C fly ash sources in the State of Iowa.

Two fly ash testing methods were utilized in this study. The first method utilized the testing scheme described in ASTM C 311 [2]. The second method studied the strength, volume stability, setting time and heat evolution properties of fly ash pastes. Specific descriptions of these tests can be found in the first progress report [1]. The overall testing scheme is shown in Figure 1.

Ashes from the Council Bluffs, Lansing, Ottumwa and Neal 4 power plants were selected to represent the range of Class C fly ashes available in Iowa. Samples of these ashes were obtained from Mr. Lon Zimmerman of Midwest Fly Ash and Materials, Inc., Sioux City, IA. The samples were obtained in accordance with ASTM C 311 [2]. Fly ash samples from Council Bluffs, Lansing and Ottumwa were subjected to all the tests shown in Figure 1. Samples of Neal 4 fly ash were only subjected to ASTM C 311 testing.

RESULTS AND DISCUSSION

Results of ASTM Physical and Chemical Testing

The results of physical and chemical analysis of the composite fly ash samples obtained during 1986 are summarized in Table I (Appendix A). The results of physical testing on each 400 ton lot of fly ash are summarized in Table II (Appendix A). Statistical results for each power plant for the calendar years 1983 thru 1985 have been published in our previous report [1]. For brevity, the statistics will not be reported again. Plots of the results of the physical testing program (i.e., moisture content, loss on ignition, 7-day cement pozzolan, specific gravity, fineness and autoclave expansion) are shown in Figures 1 thru 24 (Appendix A). The plots illustrate the uniformity of test results obtained during the four years of monitoring. The results of each specified test have been plotted on a common scale for all four of the

Physical Testing Scheme

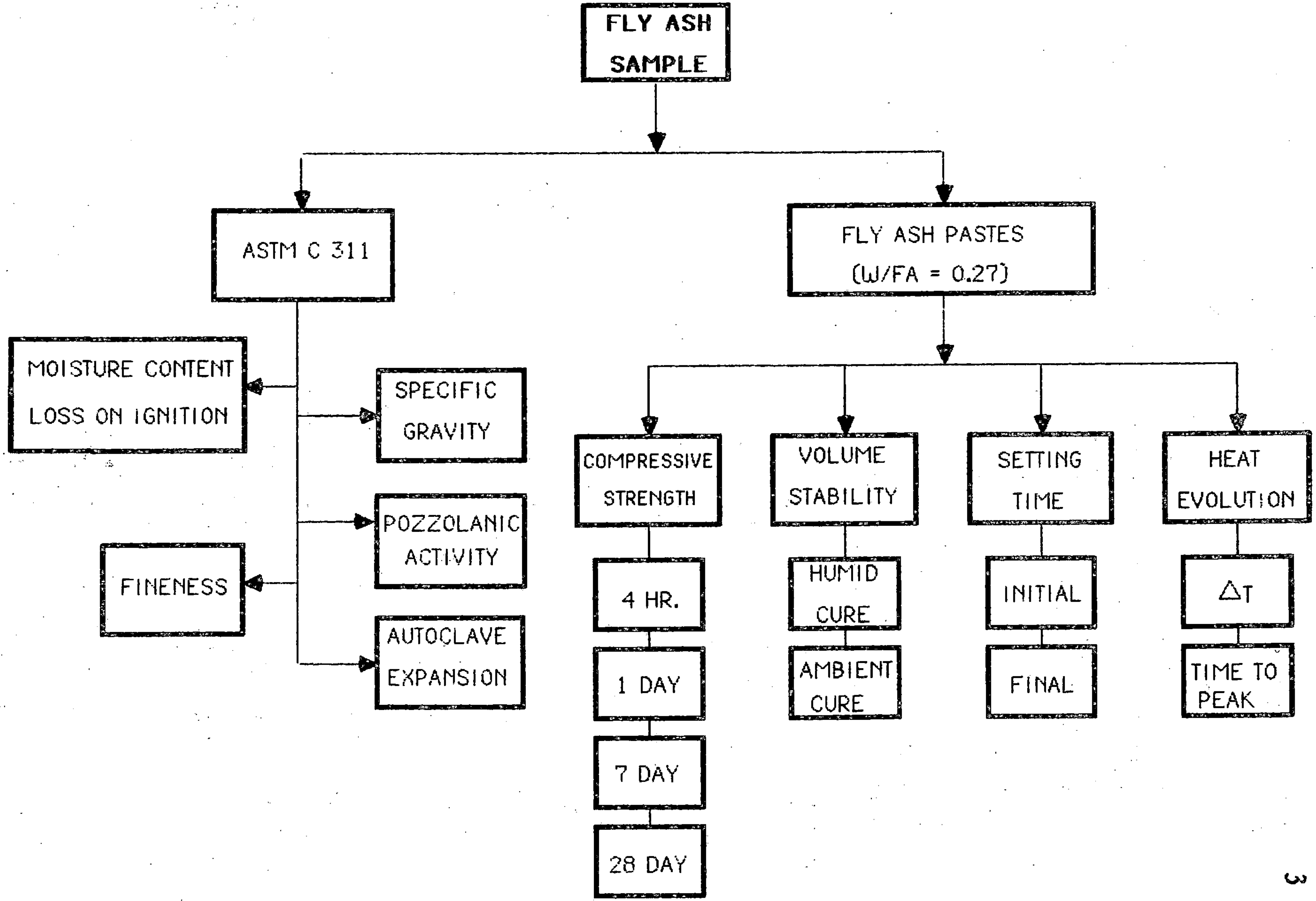

Figure 1.

power plants, this gives an indication of the variability observed between the various power plants during the four years of monitoring. It is pertinent to mention that the results of both the 7-day cement pozzolan test and the autoclave expansion test are influenced strongly by the cement used when performing the tests. Hence, Table III (Appendix A) summarizes the physical and chemical properties of the cement used during 1986.

In general, the results of the ASTM tests performed during 1986 agree with the conclusions stated in our previous report [1]. The results of this work confirm the proposal hypothesis that little variation in physical and chemical properties is observed for fly ash from a given generating station, as measured by ASTM tests.

Results of Fly Ash Paste Testing Program

Verification of physical testing methods

The first task undertaken during the second year of the project was to verify the repeatability of the testing methods for fly ash pastes. The repeatability of the paste testing methods was evaluated by making mixes on three different days using two different fly ashes. The two fly ashes that were chosen for the repeatability tests exhibited physical properties that encompassed the properties observed for most of the fly ash pastes studied so far. The two fly ash samples chosen for testing were from Ottumwa generating station (sampling date 2/25/85), and Lansing power plant (sampling date 3/29/85). The influence of water/fly ash ratio and mode of curing on the physical properties of fly ash pastes have also been studied.

In general, the repeatability tests indicated that the methods used for characterizing the physical properties of the fly ash pastes were adequate (see Tables I and II, Appendix B). Typically, the coefficients of variation for the compressive strength tests were about 10 to 20%. Hence, the tests are not precise enough to compare samples whose strengths differ by less than about 40%. It is pertinent to mention, however, that in this study, strength variations of greater than a factor of 5 (i.e., 500%) have been observed in a single power plant (Ottumwa Generating Station). Strength variations between power plants can also vary by about a factor of five. Thus, the tests were adequate for studying trends in the compressive strength of fly ash pastes.

Results of the remaining tests (i.e., volume stability, setting time and temperature rise) are also summarized in Tables I and II (Appendix B). In general, the results are reproducible on a day to day basis. In fact, the results agree reasonably well with tests performed on the same fly ash samples two years earlier (see Table III in Appendix B). There were modest discrepancies between the air cured expansion values, setting time values (both initial and final set) and the ΔT values obtained over the two year time span, but these may be attributed to changing laboratory conditions or aging of the bulk fly ash samples.

The influence of three different methods of curing on compressive strength of fly ash pastes was also investigated during the second year of the project. The three methods investigated were: (1) air curing (i.e., ambient humidity about 30 to 60% RH), (2) curing in plastic bags (i.e., moist curing, denoted as "normal" curing), and (3) curing in lime saturated water. Ambient temperatures 70 ± 5 °F (21 ± 3 °C) were utilized throughout the study. The results of the study are illustrated in Figures 1 and 2 (Appendix B). The results indicated that the moist curing methods (curing in plastic bags or under water) were needed to ensure that no long-term strength retrogression occurred. At curing times of less than about 7 days, all three curing methods produced similar results. The underlying cause of the strength retrogression in the air cured fly ash pastes is still being studied.

The results of varying the water/fly ash ratio of pastes made with the Lansing fly ash are summarized in Table IV (Appendix B). In general, the results were similar to those observed for portland cement specimens because the decrease in compressive strength was inversely proportional to the water/fly ash ratio. This is in accordance with Abram's law, a limiting case of Feret's law, which is commonly applied to cement materials [3]. A plot of 7 day compressive strength versus water/fly ash ratio is shown in Figure 3 (Appendix B). Similar results were obtained with specimens cured for other periods of time.

Air cured expansion (i.e., drying shrinkage) of the paste specimens tended to increase with water/fly ash ratio. The results of the humid cured expansion test tended to decrease with increasing water/fly ash ratio.

Setting time of the fly ash paste specimens (both initial and final set) appeared to be independent of water/fly ash ratio for the range of values studied in this investigation (w/fa = 0.27 to 0.55). This may be important to the field utilization of fly ash grouts or slurries because it indicates that some type of retarder must be used to delay the flash setting characteristics of the mixtures. Increasing the water content will increase the fluidity of the mixture but it may not significantly alter the setting time for some fly ashes.

Correlations between physical properties

The results of correlation studies using the fly ash paste data from Council Bluffs, Lansing and Ottumwa power plants are shown in Tables I, II and III, respectively. Abbreviations for the studied variables were as follows:

H4	=	4 hour compressive strength
D1	=	1 day compressive strength
D7	=	7 day compressive strength
D14	=	14 day compressive strength
D 28	=	28 day compressive strength
D56	=	56 day compressive strength
ACE	=	air cured expansion
HCE	=	humid cured expansion
IS	=	initial set time
FS	=	final set time
PKT	=	peak temperature
TIM	=	time required to reach peak temperature
DT	=	temperature rise (final temp - initial temp)

Linear correlation coefficients were generated by using the combined 1985 and 1986 paste test results from each of the individual power plants. The tables also list the significance probability of the correlation and the number of observations that were used in calculating the statistics. For example, in Table I (the Council Bluffs paste data), the Pearson correlation coefficient, r, between the 4 hour compressive strength (H4) and the one day compressive strength (D1) was 0.79516. The number directly below the correlation

Table I

1985-86 COUNCIL BLUFFS FLYASH CORRELATION MATRIX 13:47 WEDNESDAY, NOVEMBER 4, 1987

PEARSON CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	H4	D1	D7	D14	D28	D56	ACE	HCE	IS	FS	PKT	TIM	DT
H4	1.00000	0.79516	0.33773	0.55686	0.47624	0.72055	-0.01532	0.38985	0.19534	-0.08591	0.67845	-0.12637	0.54653
	0.0000	0.0001	0.0165	0.0001	0.0005	0.0011	0.9195	0.0074	0.1985	0.5703	0.0001	0.4081	0.0001
	50	49	50	47	49	17	46	46	45	46	45	45	45
D1	0.79516	1.00000	0.60390	0.73714	0.66452	0.53826	-0.15497	0.36935	-0.00789	-0.33781	0.57799	-0.48691	0.50379
	0.0001	0.0000	0.0001	0.0001	0.0001	0.0315	0.3094	0.0125	0.9595	0.0232	0.0001	0.0008	0.0005
	49	49	49	46	48	16	45	45	44	45	44	44	44
D7	0.33773	0.60390	1.00000	0.83652	0.84010	0.46224	0.05708	0.58252	-0.22540	-0.50103	0.32929	-0.61288	0.30857
	0.0165	0.0001	0.0000	0.0001	0.0001	0.0617	0.7063	0.0001	0.1366	0.0004	0.0272	0.0001	0.0392
	50	49	50	47	49	17	46	46	45	46	45	45	45
D14	0.55686	0.73714	0.83652	1.00000	0.88576	0.67112	0.05656	0.64965	-0.16050	-0.45329	0.60689	-0.61705	0.50726
	0.0001	0.0001	0.0001	0.0000	0.0001	0.0062	0.7187	0.0001	0.3099	0.0023	0.0001	0.0001	0.0005
	47	46	47	47	46	15	43	43	42	43	43	43	43
D28	0.47624	0.66452	0.84010	0.88576	1.00000	0.74128	-0.11987	0.60595	0.03792	-0.32342	0.54105	-0.52273	0.35833
	0.0005	0.0001	0.0001	0.0001	0.0000	0.0007	0.4275	0.0001	0.8047	0.0283	0.0001	0.0002	0.0156
	49	48	49	46	49	17	46	46	45	46	45	45	45
D56	0.72055	0.53826	0.46224	0.67112	0.74128	1.00000	0.12762	0.32807	0.36417	0.41111	0.71440	0.11288	0.41591
	0.0011	0.0315	0.0617	0.0062	0.0007	0.0000	0.6637	0.2522	0.1655	0.1011	0.0013	0.6662	0.0968
	17	16	17	15	17	17	14	14	16	17	17	17	17
ACE	-0.01532	-0.15497	0.05708	0.05656	-0.11987	0.12762	1.00000	0.30602	-0.34019	-0.17818	0.10052	0.05166	0.41461
	0.9195	0.3094	0.7063	0.7187	0.4275	0.6637	0.0000	0.0409	0.0275	0.2530	0.5265	0.7453	0.0063
	46	45	46	43	46	14	46	45	42	43	42	42	42
HCE	0.38985	0.36935	0.58252	0.64965	0.60595	0.32807	0.30602	1.00000	-0.10238	-0.39037	0.63974	-0.47459	0.46323
	0.0074	0.0125	0.0001	0.0001	0.0001	0.2522	0.0409	0.0000	0.5188	0.0097	0.0001	0.0015	0.0020
	46	45	46	43	46	14	45	46	42	43	42	42	42
IS	0.19534	-0.00789	-0.22540	-0.16050	0.03792	0.36417	-0.34019	-0.10238	1.00000	0.82370	0.18146	0.33200	-0.10450
	0.1985	0.9595	0.1366	0.3099	0.8047	0.1655	0.0275	0.5188	0.0000	0.0001	0.2442	0.0296	0.5048
	45	44	45	42	45	16	42	42	45	45	43	43	43
FS	-0.08591	-0.33781	-0.50103	-0.45329	-0.32342	0.41111	-0.17818	-0.39037	0.82370	1.00000	-0.18116	0.63226	-0.25366
	0.5703	0.0232	0.0004	0.0023	0.0283	0.1011	0.2530	0.0097	0.0001	0.0000	0.2392	0.0001	0.0966
	46	45	46	43	46	17	43	43	45	46	44	44	44
PKT	0.67845	0.57799	0.32929	0.60689	0.54105	0.71440	0.10052	0.63974	0.18146	-0.18116	1.00000	-0.43619	0.65468
	0.0001	0.0001	0.0272	0.0001	0.0001	0.0013	0.5265	0.0001	0.2442	0.2392	0.0000	0.0027	0.0001
	45	44	45	43	45	17	42	42	43	44	45	45	45
TIM	-0.12637	-0.48691	-0.61288	-0.61705	-0.52273	0.11288	0.05166	-0.47459	0.33200	0.63226	-0.43619	1.00000	-0.32232
	0.4081	0.0008	0.0001	0.0001	0.0002	0.6662	0.7453	0.0015	0.0296	0.0001	0.0027	0.0000	0.0308
	45	44	45	43	45	17	42	42	43	44	45	45	45
DT	0.54653	0.50379	0.30857	0.50726	0.35833	0.41591	0.41461	0.46323	-0.10450	-0.25366	0.65468	-0.32232	1.00000
	0.0001	0.0005	0.0392	0.0005	0.0156	0.0968	0.0063	0.0020	0.5048	0.0966	0.0001	0.0308	0.0000
	45	44	45	43	45	17	42	42	43	44	45	45	45

Table II

1985-86 LANSING FLYASH CORRELATION MATRIX 13:42 WEDNESDAY, NOVEMBER 4, 1987 3

PEARSON CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	H4	D1	D7	D14	D28	D56	ACE	HCE	IS	FS	PKT	TIM	DT
H4	1.00000	0.82218	0.80196	0.81858	0.84535	0.88306	-0.34114	0.12402	-0.18327	-0.68966	0.73837	-0.25088	0.78112
	0.0000	0.0001	0.0001	0.0001	0.0001	0.0007	0.0881	0.5377	0.3913	0.0002	0.0001	0.2601	0.0001
	29	29	29	29	29	10	26	27	24	24	22	22	22
D1	0.82218	1.00000	0.88661	0.75855	0.82421	0.72546	-0.18382	0.14491	-0.16512	-0.55683	0.67035	-0.47509	0.72483
	0.0001	0.0000	0.0001	0.0001	0.0001	0.0176	0.3587	0.4619	0.4303	0.0039	0.0005	0.0220	0.0001
	29	30	29	29	30	10	27	28	25	25	23	23	23
D7	0.80196	0.88661	1.00000	0.79580	0.85576	0.68696	-0.18744	0.23728	-0.11141	-0.53770	0.63491	-0.44758	0.65151
	0.0001	0.0001	0.0000	0.0001	0.0001	0.0282	0.3592	0.2334	0.6043	0.0067	0.0015	0.0367	0.0010
	29	29	29	29	29	10	26	27	24	24	22	22	22
D14	0.81858	0.75855	0.79580	1.00000	0.88191	0.78373	-0.39569	0.38106	-0.20541	-0.55991	0.76467	-0.32984	0.73467
	0.0001	0.0001	0.0001	0.0000	0.0001	0.0073	0.0454	0.0499	0.3356	0.0045	0.0001	0.1338	0.0001
	29	29	29	29	29	10	26	27	24	24	22	22	22
D28	0.84535	0.82421	0.85576	0.88191	1.00000	0.65810	-0.40609	0.37050	0.04585	-0.48449	0.64019	-0.46774	0.71319
	0.0001	0.0001	0.0001	0.0001	0.0000	0.0386	0.0320	0.0479	0.8240	0.0121	0.0008	0.0212	0.0001
	29	30	29	29	31	10	28	29	26	26	24	24	24
D56	0.88306	0.72546	0.68696	0.78373	0.65810	1.00000	-0.17987	0.44959	0.44201	0.46478	0.61244	-0.39605	0.72833
	0.0007	0.0176	0.0282	0.0073	0.0386	0.0000	0.6190	0.1924	0.2009	0.1759	0.0598	0.2572	0.0169
	10	10	10	10	10	10	10	10	10	10	10	10	10
ACE	-0.34114	-0.18382	-0.18744	-0.39569	-0.40609	-0.17987	1.00000	-0.32171	0.00748	-0.01435	-0.17085	-0.09599	-0.02426
	0.0881	0.3587	0.3592	0.0454	0.0320	0.6190	0.0000	0.0950	0.9730	0.9482	0.4471	0.6709	0.9146
	26	27	26	26	28	10	28	28	23	23	22	22	22
HCE	0.12402	0.14491	0.23728	0.38106	0.37050	0.44959	-0.32171	1.00000	0.27308	0.10972	0.27571	-0.29583	0.23634
	0.5377	0.4619	0.2334	0.0499	0.0479	0.1924	0.0950	0.0000	0.1967	0.6098	0.2143	0.1813	0.2896
	27	28	27	27	29	10	28	29	24	24	22	22	22
IS	-0.18327	-0.16512	-0.11141	-0.20541	0.04585	0.44201	0.00748	0.27308	1.00000	0.24091	0.21369	-0.25460	0.27194
	0.3913	0.4303	0.6043	0.3356	0.8240	0.2009	0.9730	0.1967	0.0000	0.2358	0.3523	0.2654	0.2331
	24	25	24	24	26	10	23	24	26	26	21	21	21
FS	-0.68966	-0.55683	-0.53770	-0.55991	-0.48449	0.46478	-0.01435	0.10972	0.24091	1.00000	-0.72662	0.01198	-0.68626
	0.0002	0.0039	0.0067	0.0045	0.0121	0.1759	0.9482	0.6098	0.2358	0.0000	0.0002	0.9589	0.0006
	24	25	24	24	26	10	23	24	26	26	21	21	21
PKT	0.73837	0.67035	0.63491	0.76467	0.64019	0.61244	-0.17085	0.27571	0.21369	-0.72662	1.00000	-0.42838	0.90813
	0.0001	0.0005	0.0015	0.0001	0.0008	0.0598	0.4471	0.2143	0.3523	0.0002	0.0000	0.0367	0.0001
	22	23	22	22	24	10	22	22	21	21	24	24	24
TIM	-0.25088	-0.47509	-0.44758	-0.32984	-0.46774	-0.39605	-0.09599	-0.29583	-0.25460	0.01198	-0.42838	1.00000	-0.46949
	0.2601	0.0220	0.0367	0.1338	0.0212	0.2572	0.6709	0.1813	0.2654	0.9589	0.0367	0.0000	0.0206
	22	23	22	22	24	10	22	22	21	21	24	24	24
DT	0.78112	0.72483	0.65151	0.73467	0.71319	0.72833	-0.02426	0.23634	0.27194	-0.68626	0.90813	-0.46949	1.00000
	0.0001	0.0001	0.0010	0.0001	0.0001	0.0169	0.9146	0.2896	0.2331	0.0006	0.0001	0.0206	0.0000
	22	23	22	22	24	10	22	22	21	21	24	24	24

Table III

1985-86 OTTUMWA FLYASH CORRELATION MATRIX 13:10 FRIDAY, JUNE 5, 1987 2

PEARSON CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	H4	D1	D3	D7	D14	D28	ACE	HCE	IS	FS	PKT	TIM	DT
H4	1.00000	0.43193	0.22793	0.18024	0.20144	0.15580	-0.22076	-0.09611	-0.12512	-0.19741	0.34480	0.27244	0.58892
	0.0000	0.0001	0.0477	0.0929	0.0598	0.1545	0.0521	0.3964	0.2510	0.0685	0.0012	0.0112	0.0001
	88	81	76	88	88	85	78	80	86	86	86	86	86
D1	0.43193	1.00000	0.90259	0.76609	0.77599	0.78123	-0.34708	0.59430	-0.08484	-0.20470	0.15874	-0.07179	0.27305
	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001	0.0010	0.0001	0.4037	0.0421	0.1224	0.4870	0.0071
	81	101	72	100	99	99	87	93	99	99	96	96	96
D3	0.22793	0.90259	1.00000	0.91647	0.83810	0.91845	-0.49996	0.75509	0.11093	-0.20407	0.08237	-0.16207	0.23345
	0.0477	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.3401	0.0770	0.4763	0.1591	0.0410
	76	72	78	78	78	77	70	73	76	76	77	77	77
D7	0.18024	0.76609	0.91647	1.00000	0.90593	0.95621	-0.42702	0.60487	-0.06813	-0.26153	0.05976	-0.20649	0.17839
	0.0929	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001	0.4878	0.0068	0.5508	0.0373	0.0728
	88	100	78	108	106	105	93	99	106	106	102	102	102
D14	0.20144	0.77599	0.83810	0.90593	1.00000	0.93137	-0.46576	0.67111	-0.07307	-0.23162	0.09985	-0.22891	0.21584
	0.0598	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.4588	0.0174	0.3205	0.0213	0.0302
	88	99	78	106	107	104	93	98	105	105	101	101	101
D28	0.15580	0.78123	0.91845	0.95621	0.93137	1.00000	-0.45373	0.66846	-0.08040	-0.26609	0.00672	-0.24100	0.14947
	0.1545	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.4172	0.0063	0.9471	0.0157	0.1377
	85	99	77	105	104	106	93	99	104	104	100	100	100
ACE	-0.22076	-0.34708	-0.49996	-0.42702	-0.46576	-0.45373	1.00000	-0.19219	-0.26413	-0.07538	0.02448	-0.12550	-0.11348
	0.0521	0.0010	0.0001	0.0001	0.0001	0.0001	0.0000	0.0664	0.0110	0.4751	0.8199	0.2412	0.2897
	78	87	70	93	93	93	94	92	92	92	89	89	89
HCE	-0.09611	0.59430	0.75509	0.60487	0.67111	0.66846	-0.19219	1.00000	-0.08427	-0.23945	-0.15013	-0.37810	-0.12149
	0.3964	0.0001	0.0001	0.0001	0.0001	0.0001	0.0664	0.0000	0.4094	0.0176	0.1465	0.0002	0.2409
	80	93	73	99	98	99	92	100	98	98	95	95	95
IS	-0.12512	-0.08484	0.11093	-0.06813	-0.07307	-0.08040	-0.26413	-0.08427	1.00000	0.74173	-0.29774	0.50165	-0.34810
	0.2510	0.4037	0.3401	0.4878	0.4588	0.4172	0.0110	0.4094	0.0000	0.0001	0.0025	0.0001	0.0004
	86	99	76	106	105	104	92	98	107	107	101	101	101
FS	-0.19741	-0.20470	-0.20407	-0.26153	-0.23162	-0.26609	-0.07538	-0.23945	0.74173	1.00000	-0.26834	0.69496	-0.35881
	0.0685	0.0421	0.0770	0.0068	0.0174	0.0063	0.4751	0.0176	0.0001	0.0000	0.0067	0.0001	0.0002
	86	99	76	106	105	104	92	98	107	107	101	101	101
PKT	0.34480	0.15874	0.08237	0.05976	0.09985	0.00672	0.02448	-0.15013	-0.29774	-0.26834	1.00000	-0.18226	0.71196
	0.0012	0.1224	0.4763	0.5508	0.3205	0.9471	0.8199	0.1465	0.0025	0.0067	0.0000	0.0654	0.0001
	86	96	77	102	101	100	89	95	101	101	103	103	103
TIM	0.27244	-0.07179	-0.16207	-0.20649	-0.22891	-0.24100	-0.12550	-0.37810	0.50165	0.69496	-0.18226	1.00000	-0.19243
	0.0112	0.4870	0.1591	0.0373	0.0213	0.0157	0.2412	0.0002	0.0001	0.0001	0.0654	0.0000	0.0515
	86	96	77	102	101	100	89	95	101	101	103	103	103
DT	0.58892	0.27305	0.23345	0.17839	0.21584	0.14947	-0.11348	-0.12149	-0.34810	-0.35881	0.71196	-0.19243	1.00000
	0.0001	0.0071	0.0410	0.0728	0.0302	0.1377	0.2897	0.2409	0.0004	0.0002	0.0001	0.0515	0.0000
	86	96	77	102	101	100	89	95	101	101	103	103	103

coefficient (0.0001 in this instance) is the significance probability of the correlation. This value indicates that the linear correlation between H4 and D1 was significant (i.e., we can reject the null hypothesis that no linear relationship (r=0) exists between H4 and D1). We have arbitrarily adopted a 99% confidence interval for accepting or rejecting potential correlations, this corresponds to a significance probability value of 0.005 or less. The integer directly below the significance probability of the correlation value denotes the number of samples used in the statistical calculations (49 observations in this instance). Please note that all of the correlation matrices are symmetric about their main diagonals.

In general, the individual power plants exhibited similar trends. For example, the short term strengths of all the fly ash paste specimens correlated well to the 14 and 28 day compressive strengths. Also, humid cured expansion generally correlated well with the 28 day strength. Hence, all of the fly ash paste test results were combined into a single data file and the correlation calculations were repeated. The combined fly ash correlation matrix is listed in Table IV.

Strong correlations were observed between several of the variables studied in this project. Correlation coefficients greater than 0.7 have been circled (see Table IV). In general, the results are in agreement with the potential correlations that were described in our first progress report [1]. However, they are much more statistically sound because the number of observations has nearly doubled since that time.

One of the more interesting trends that was observed is illustrated in Figure 2. The trend is important because it indicates that a fairly reliable linear relationship exists between the 7 day and 28 day compressive strengths of the fly ash pastes (the graph contains 182 data points). Linear

Table IV

1985-86 TOTAL FLYASH CORRELATION MATRIX 13:52 WEDNESDAY, NOVEMBER 4, 1987

PEARSON CORRELATION COEFFICIENTS / PROB > |R| UNDER HO:RHO=O / NUMBER OF OBSERVATIONS

	H4	D1	D7	D14	D28	D56	ACE	HCE	IS	FS	PKT	TIM	DT
H4	1.00000	0.91727	0.71059	0.75057	0.73012	0.49975	-0.41706	0.47374	-0.59629	-0.63082	0.89996	-0.45463	0.90818
	0.0000	0.0001	0.0001	0.0001	0.0001	0.0080	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	167	159	167	164	163	27	150	153	155	156	153	153	153
D1	0.91727	1.00000	0.84500	0.83695	0.83464	0.34844	-0.48421	0.48498	-0.53595	-0.59473	0.80989	-0.48595	0.82929
	0.0001	0.0000	0.0001	0.0001	0.0001	0.0811	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	159	180	178	174	177	26	159	166	168	169	163	163	163
D7	0.71059	0.84500	1.00000	0.92216	0.93464	0.32845	-0.44758	0.60735	-0.46826	-0.57205	0.63390	-0.51918	0.65541
	0.0001	0.0001	0.0000	0.0001	0.0001	0.0944	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	167	178	187	182	183	27	165	172	175	176	169	169	169
D14	0.75057	0.83695	0.92216	1.00000	0.94781	0.54260	-0.47774	0.66914	-0.48895	-0.58297	0.71536	-0.54283	0.71687
	0.0001	0.0001	0.0001	0.0000	0.0001	0.0051	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	164	174	182	183	179	25	162	168	171	172	166	166	166
D28	0.73012	0.83464	0.93464	0.94781	1.00000	0.67899	-0.51497	0.66343	-0.47144	-0.58763	0.70475	-0.54653	0.70547
	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	163	177	183	179	186	27	167	174	175	176	169	169	169
D56	0.49975	0.34844	0.32845	0.54260	0.67899	1.00000	0.09331	0.34160	0.39023	0.42780	0.52134	-0.05477	0.33864
	0.0080	0.0811	0.0944	0.0051	0.0001	0.0000	0.6645	0.1023	0.0487	0.0260	0.0053	0.7862	0.0840
	27	26	27	25	27	27	24	24	26	27	27	27	27
ACE	-0.41706	-0.48421	-0.44758	-0.47774	-0.51497	0.09331	1.00000	-0.18533	0.12399	0.23772	-0.35368	0.12482	-0.32537
	0.0001	0.0001	0.0001	0.0001	0.0001	0.6645	0.0000	0.0172	0.1218	0.0026	0.0001	0.1242	0.0001
	150	159	165	162	167	24	168	165	157	158	153	153	153
HCE	0.47374	0.48498	0.60735	0.66914	0.66343	0.34160	-0.18533	1.00000	-0.32003	-0.43748	0.54712	-0.50430	0.50876
	0.0001	0.0001	0.0001	0.0001	0.0001	0.1023	0.0172	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001
	153	166	172	168	174	24	165	175	164	165	159	159	159
IS	-0.59629	-0.53595	-0.46826	-0.48895	-0.47144	0.39023	0.12399	-0.32003	1.00000	0.83813	-0.57485	0.62440	-0.60555
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0487	0.1218	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001
	155	168	175	171	175	26	157	164	178	178	165	165	165
FS	-0.63082	-0.59473	-0.57205	-0.58297	-0.58763	0.42780	0.23772	-0.43748	0.83813	1.00000	-0.63854	0.74224	-0.65154
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0260	0.0026	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001
	156	169	176	172	176	27	158	165	178	179	166	166	166
PKT	0.89996	0.80989	0.63390	0.71536	0.70475	0.52134	-0.35368	0.54712	-0.57485	-0.63854	1.00000	-0.54389	0.92984
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0053	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001
	153	163	169	166	169	27	153	159	165	166	172	172	172
TIM	-0.45463	-0.48595	-0.51918	-0.54283	-0.54653	-0.05477	0.12482	-0.50430	0.62440	0.74224	-0.54389	1.00000	-0.53143
	0.0001	0.0001	0.0001	0.0001	0.0001	0.7862	0.1242	0.0001	0.0001	0.0001	0.0001	0.0000	0.0001
	153	163	169	166	169	27	153	159	165	166	172	172	172
DT	0.90818	0.82929	0.65541	0.71687	0.70547	0.33864	-0.32537	0.50876	-0.60555	-0.65154	0.92984	-0.53143	1.00000
	0.0001	0.0001	0.0001	0.0001	0.0001	0.0840	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0000
	153	163	169	166	169	27	153	159	165	166	172	172	172

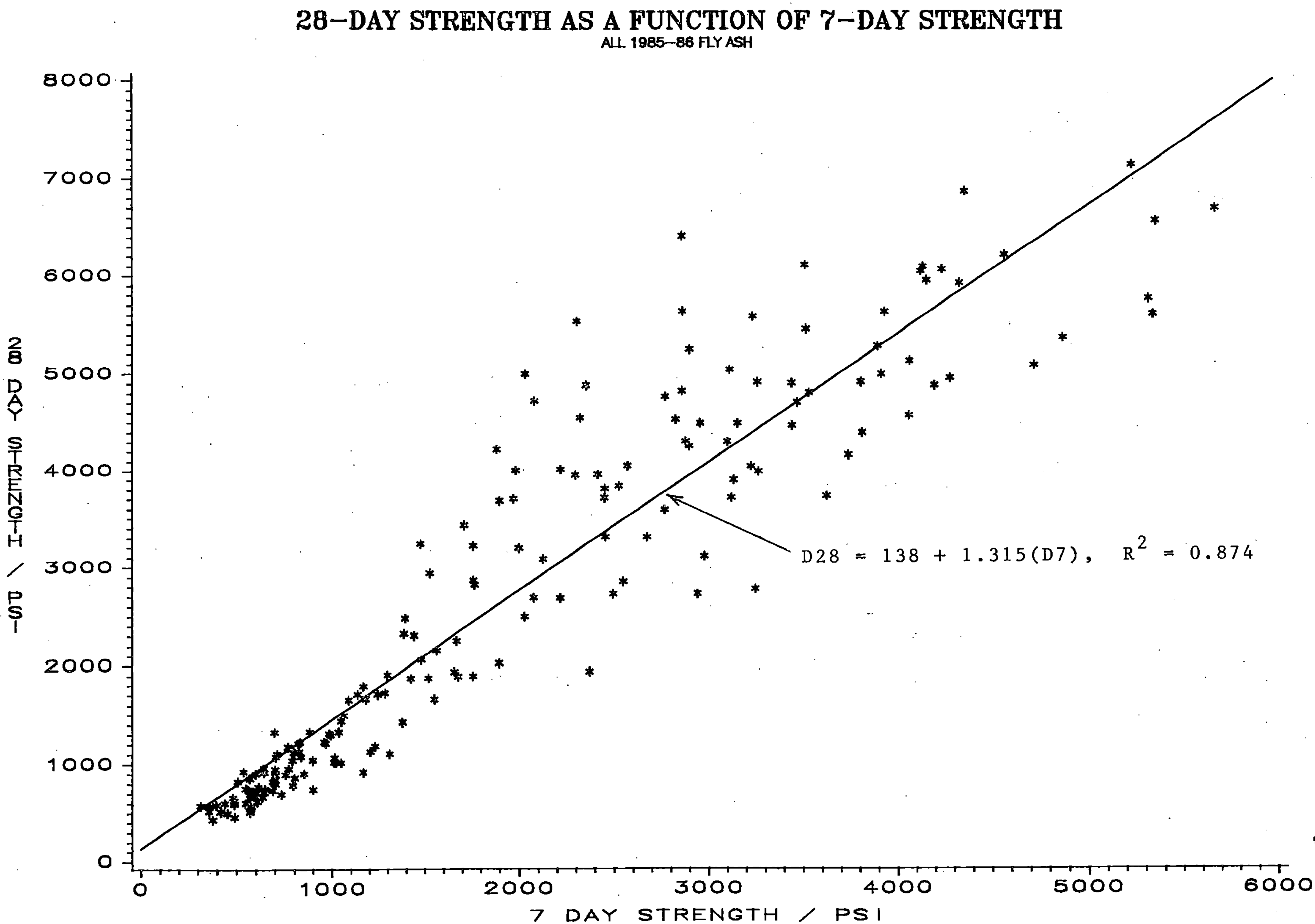

Figure 2. Relationship between 7-day and 28-day OGS paste strengths.

regression of the data yielded the equation listed in Figure 2. The intercept was not statistically significant so the linear relationship can be simplified to (assuming 2 significant digits):

28 day strength = 1.3 x 7 day strength.

The scatter of points around the regressed line appeared to increase as paste compressive strengths increased, but part of the scatter can be attributed to the poor precision obtained from the 1 x 1 inch cubes. The equation can be made to produce more conservative estimates of the 28 day compressive strengths by using a multiplier of 1.1 or 1.2 in place of the 1.3.

Fly Ash Trends at Ottumwa Generating Station

The bulk of the Materials Analysis and Research Laboratory fly ash data base consists of information about samples obtained from Ottumwa Generating Station(OGS). Also, OGS personnel have been very receptive to providing power plant operating conditions and maintenance schedules to Iowa State researchers. Hence, the current state of knowledge about the fly ash produced at OGS is well ahead of the other Iowa power plants. Since OGS is similar to two other Iowa power plants (namely the Council Bluffs and Neal 4 generating stations) it is possible that trends identified at OGS may also be present at the other power plants.

OGS produces about 80,000 tons per year of high-calcium fly ash having a nominal analytical CaO content of about 25%. The power plant burns low sulfur, sub-bituminous coal from the Powder River Basin near Gillette, Wyoming. Sodium carbonate is routinely added to the raw coal feed to enhance the performance of the power plants hot-side electrostatic precipitators. The pertinent details concerning OGS, such as net generating capacity, maintenance schedule, etc., are summarized in Appendix C. It is interesting to note, that about 43% of the fly ash produced by OGS in 1986 was utilized in some manner.

As mentioned in an earlier report [1], the compressive strength of Ottumwa fly ash pastes change drastically as a function of time. A plot of the 7 day compressive strength of OGS fly ash pastes versus sampling date is shown in Figure 3. It is evident that the major fluctuations in compressive strength occurs during the late spring or late fall months of the calendar year. These fluctuations in compressive strength correspond roughly to the OGS maintenance schedule. A plot of the 7 day compressive strength OGS fly ash versus sampling date is shown in Figure 4. The solid bars on the time axis correspond to the biannual maintenance shutdowns at OGS. The average monthly sodium carbonate feed rate, expressed in pounds per ton of coal, has also been plotted on Figure 4. It is apparent that the power plant operating parameters (both sodium carbonate feed rate and routine maintenance periods) influence the strength properties of the OGS fly ash pastes. It must be mentioned that the maintenance cycle is not independent of the sodium carbonate feed rate. In fact, the two are directly related because the sodium carbonate doping is utilized to increase the length of time that the power plant can operate within EPA air quality specifications. Hence, the sodium carbonate feed rate is normally cycled during the generating year. After a maintenance shutdown, during which the electrostatic precipitators are washed out, the power plant needs little (or no) sodium carbonate doping to meet EPA specifications. However, when the power plant is approaching a maintenance shutdown, a high sodium carbonate feed rate is normally needed to stay within EPA guidelines. When the sodium carbonate feed rate gets large enough to cause excessive boiler

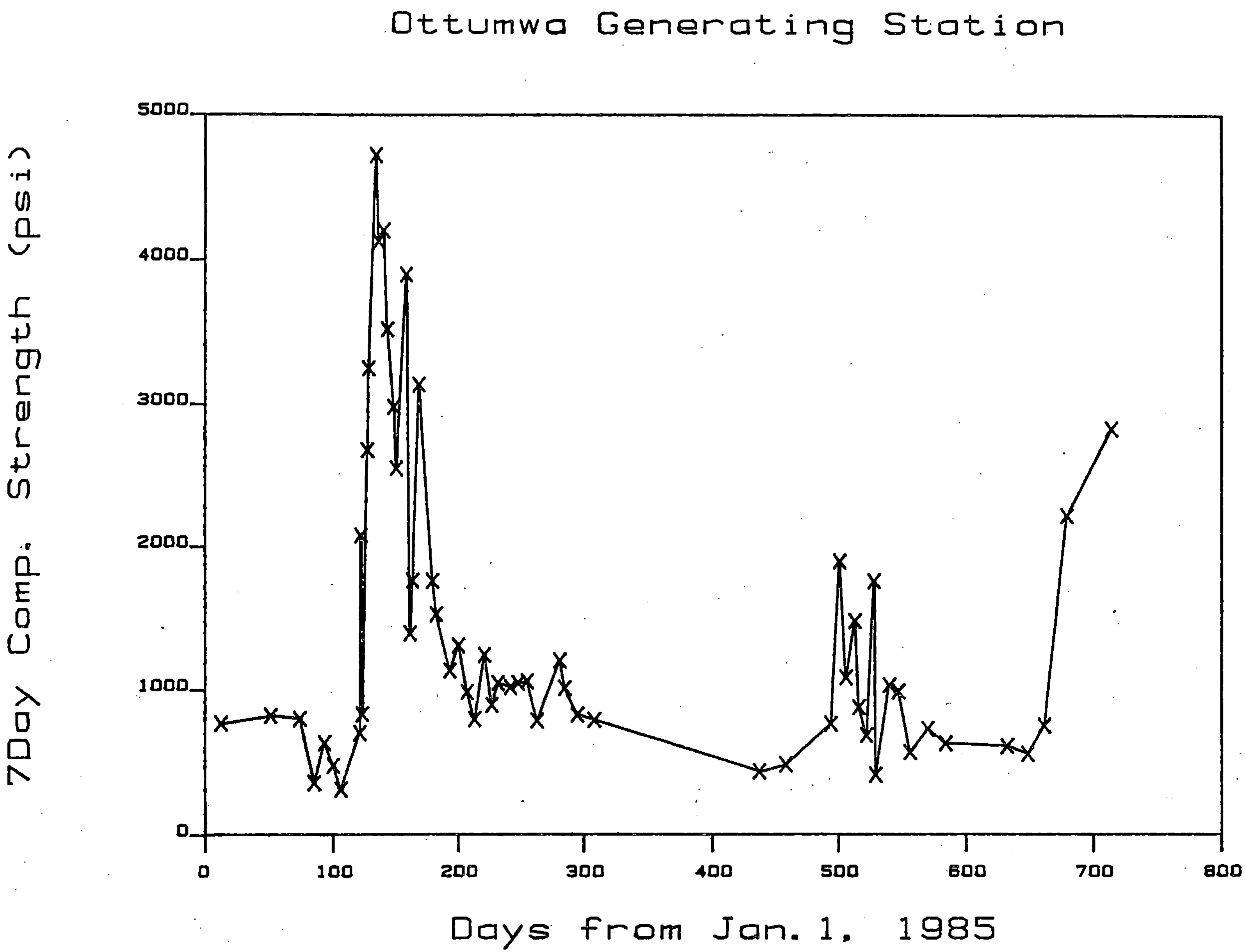

Figure 3. 7-day compressive strength of OGS fly ash pastes.

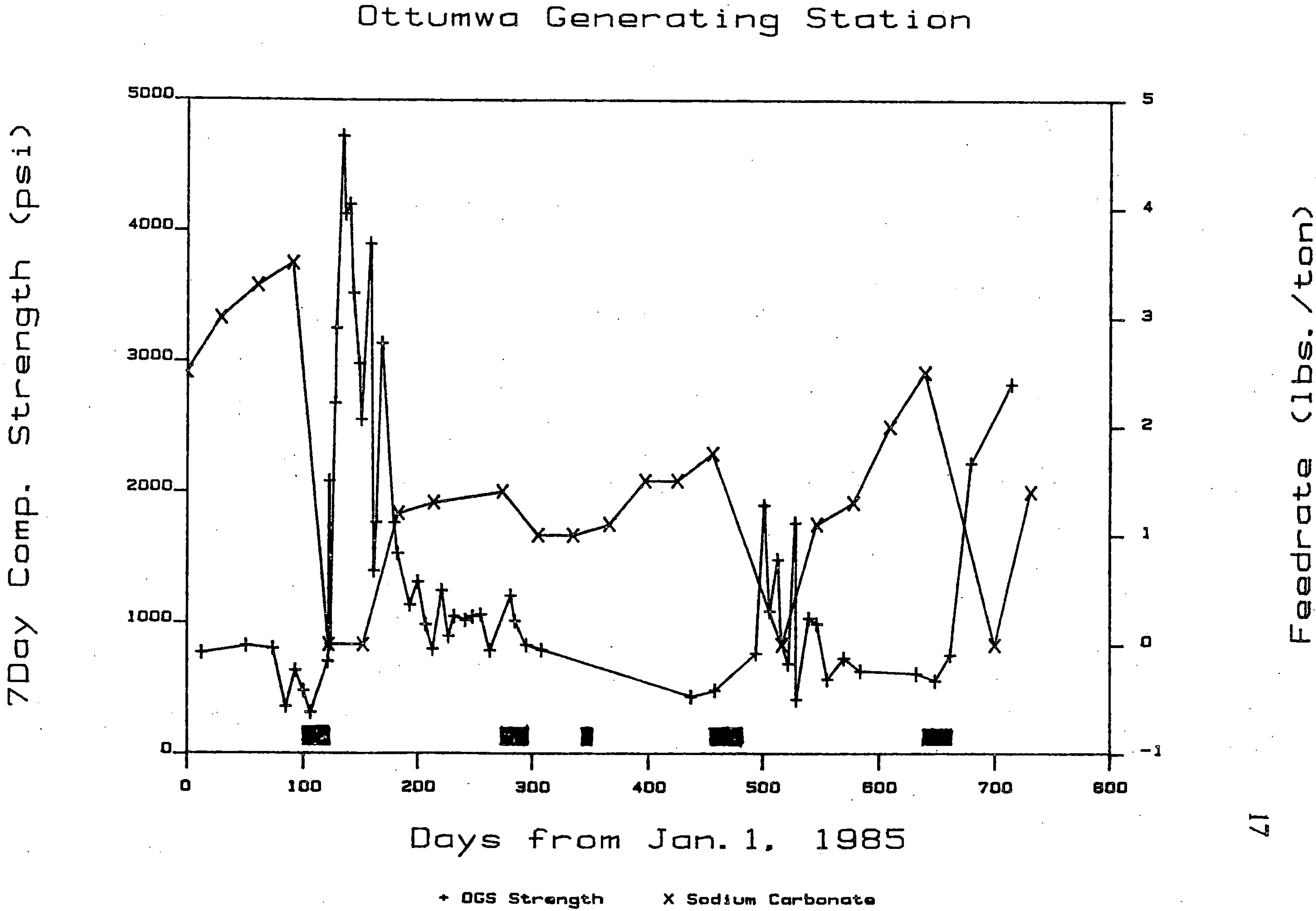

Figure 4. Overlay of 7-day compressive strength and OGS sodium carbonate feedrate versus sampling date.

slagging (typically between 3 and 4 pounds of sodium carbonate per ton of raw coal) the power plant will shutdown for cleaning. A plot of the bulk fly ash sodium oxide content versus sampling time is shown in Figure 5. The average monthly sodium carbonate feed rate used at OGS, has also been plotted in Figure 5. The sodium carbonate feed rate appears to be influencing the amount of sodium oxide present in the fly ash. Sulfur content of the fly ash exhibited a similar behavior, although it did not correspond as well to OGS sodium carbonate feed rate. The remaining elements monitored in this study (Si, Al, Fe, Mg, Ca, P, Ti, Na and K), did not indicate any consistent trends.

Detailed studies have been conducted on the basic mechanism of strength gain in OGS fly ash pastes. Extensive use has been made of x-ray diffraction, and x-ray fluorescence analytical techniques that have been described in an earlier report [1]. The general chemical reactions that appear to dominate the strength properties of the OGS fly ash pastes can be illustrated by utilizing two samples that were taken at different dates. The first sample, OTT022585, was obtained about one month before a maintenance shutdown, while the power plant was using a sodium carbonate feed rate of slightly more than 3 pounds per ton of coal. The second sample, OTT060785, was obtained about one month after completion of the maintenance shutdown, while the power plant was not adding sodium carbonate to the raw coal feed.

The results of bulk chemical analysis as determined with quantitative X-ray fluorescence are listed in Table V. Also, the results of the ASTM C 311 and fly ash paste tests have been listed in the table. The physical properties of the two fly ash pastes, especially the strength properties, were quite different. The bulk chemistries of the two fly ash samples were similar, but

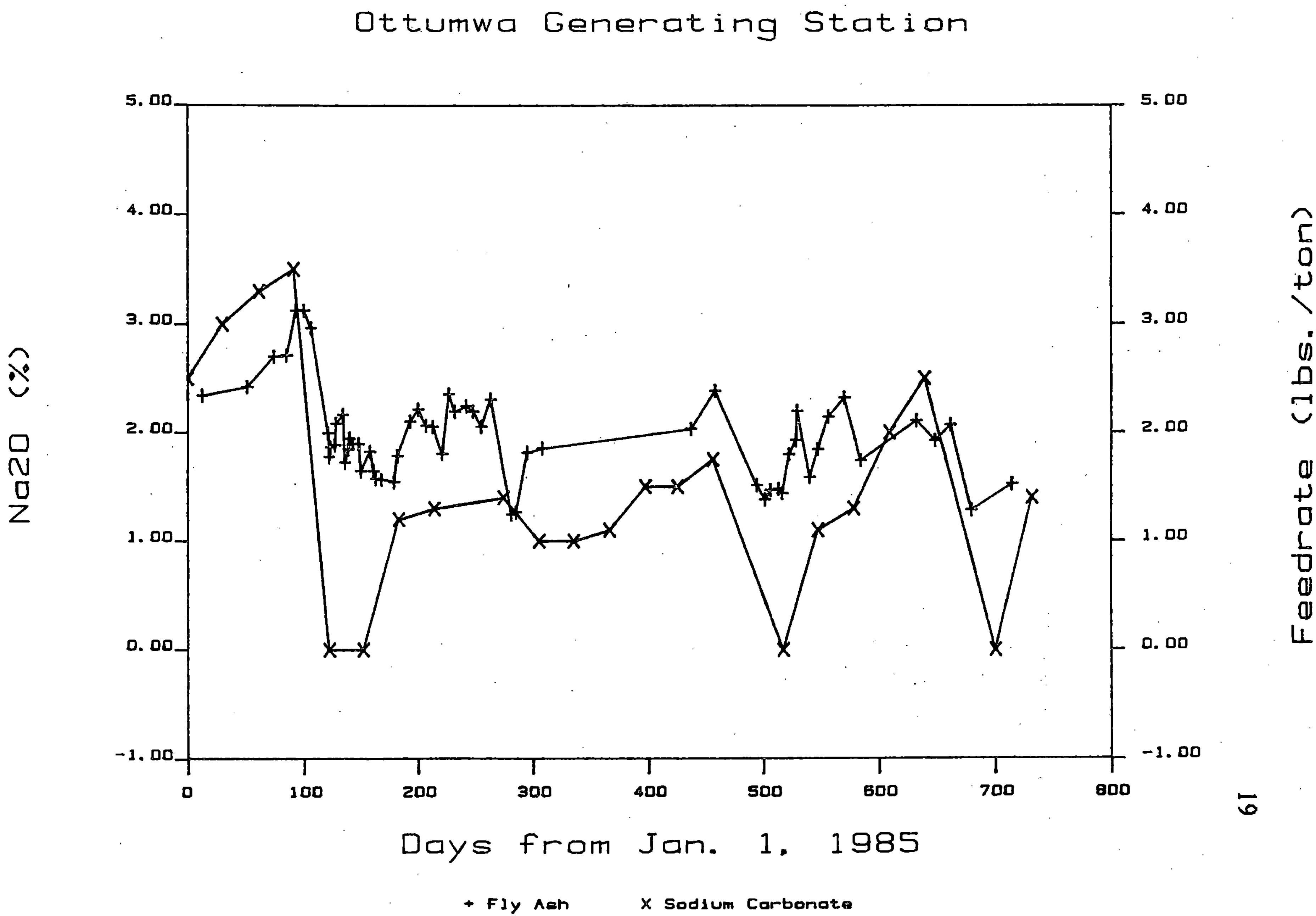

Figure 5. Fly ash sodium oxide content and OGS sodium carbonate feedrate versus sampling date.

Table V

Results of chemical and physical analysis of two OGS fly ash samples

Chemical composition

oxide	OTT022585	OTT060785
SiO_2	34.7	32.6
Al_2O_3	19.9	20.0
Fe_2O_3	5.43	6.46
SO_3	3.34	2.47
CaO	25.5	26.7
MgO	4.9	4.8
Na_2O	2.77	1.79
K_2O	0.42	0.36
TiO_2	1.56	1.55
P_2O_5	1.13	2.10
MnO	0.04	0.03
BaO	0.74	0.94
SrO	0.37	0.46
LOI	0.39	0.41
sum	101.2	100.7

Physical properties (fly ash pastes, w/fa = 0.27)

Compressive strength (psi)		
1-day	550	2020
7-day	700	3900
28-day	950	5270
Setting time (min.)		
Initial	12	8
Final	18	13
Volume stability (% expansion)		
Humid Cured	-0.04	0.07
Air Cured	-0.01	-0.06
Temperature rise		
ΔT (°C)	7.5	6.1
Time to Peak(min)	57	27

Table V (continued)

	OTT022585	OTT060785
ASTM C 311 tests		
Moisture Content (%)	0.0	0.0
Loss on Ignition (%)	0.4	0.2
Fineness (%)	11.3	9.8
7-day Pozzolan (%)	87	96
Autoclave Exp. (%)	0.06	0.07
Specific Gravity	2.58	2.69

there were distinct differences in the sodium, sulfur and phosphorous contents of the samples.

X-ray diffractograms of the two raw (as received) OGS fly ash samples are shown in Figure 6. Mineralogically, the two samples were similar since they both contained α-quartz, anhydrite, lime, periclase and a mineral similar to tricalcium aluminate. The diffraction peak at about 3.75 Å has tentatively been identified as tetracalcium trialuminate sulfate. The diffractograms indicated that OTT022585 (the "weak" fly ash) contained more anhydrite and tetracalcium trialuminate sulfate than did OTT060785 (the "strong" fly ash). This is in general agreement with the bulk chemical assays of the fly ashes.

The results of X-ray diffraction analysis of the two fly ash pastes after 7 days of moist curing, are shown in Figure 7. The major hydration product present in the diffractogram of the strong fly ash paste was stratlingite. Both monosulfoaluminate and ettringite were also identified in the diffractogram. In contrast, ettringite was the major hydration product

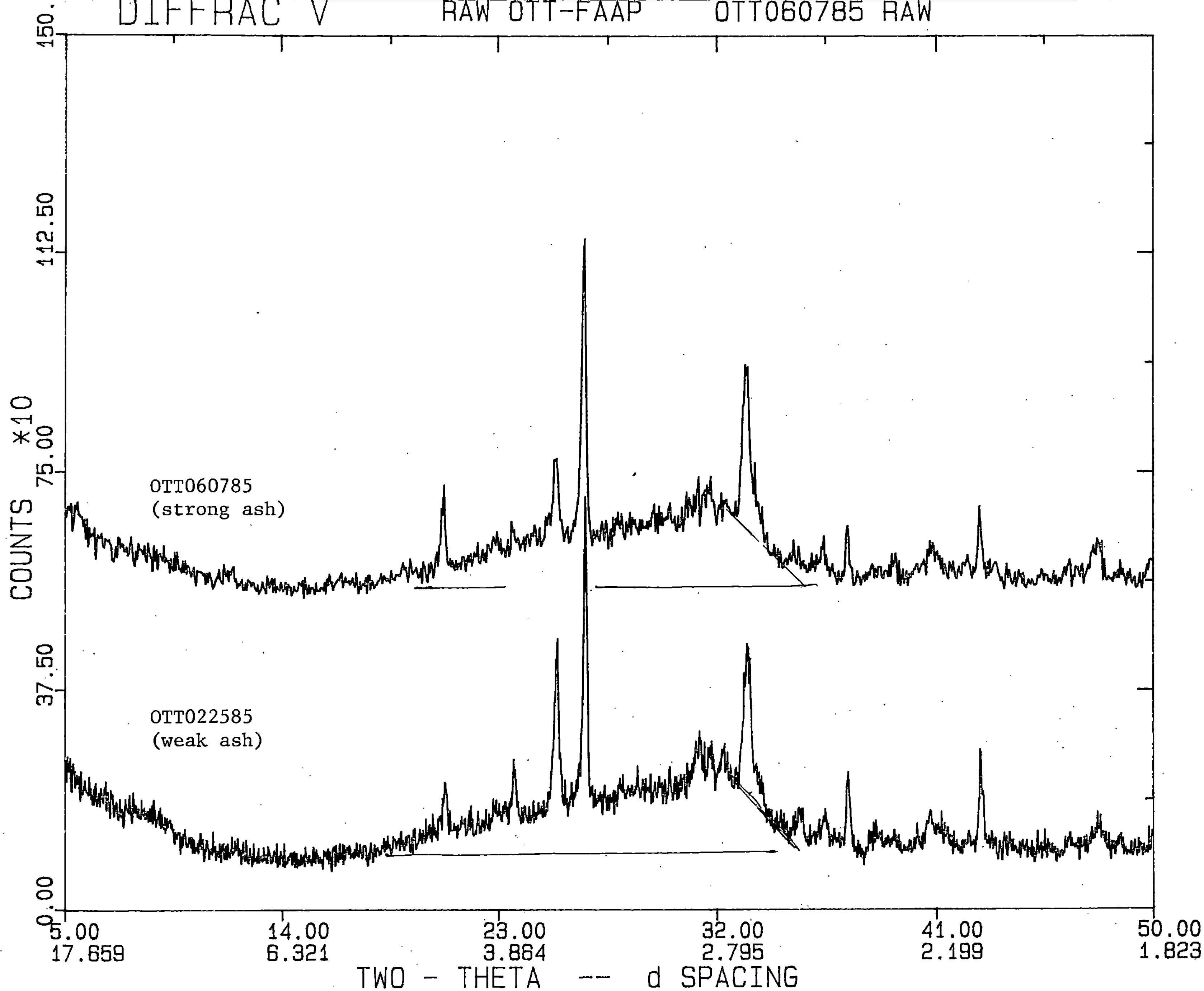

Figure 6. X-ray diffractograms of the two raw (as-received) OGS fly ashes.

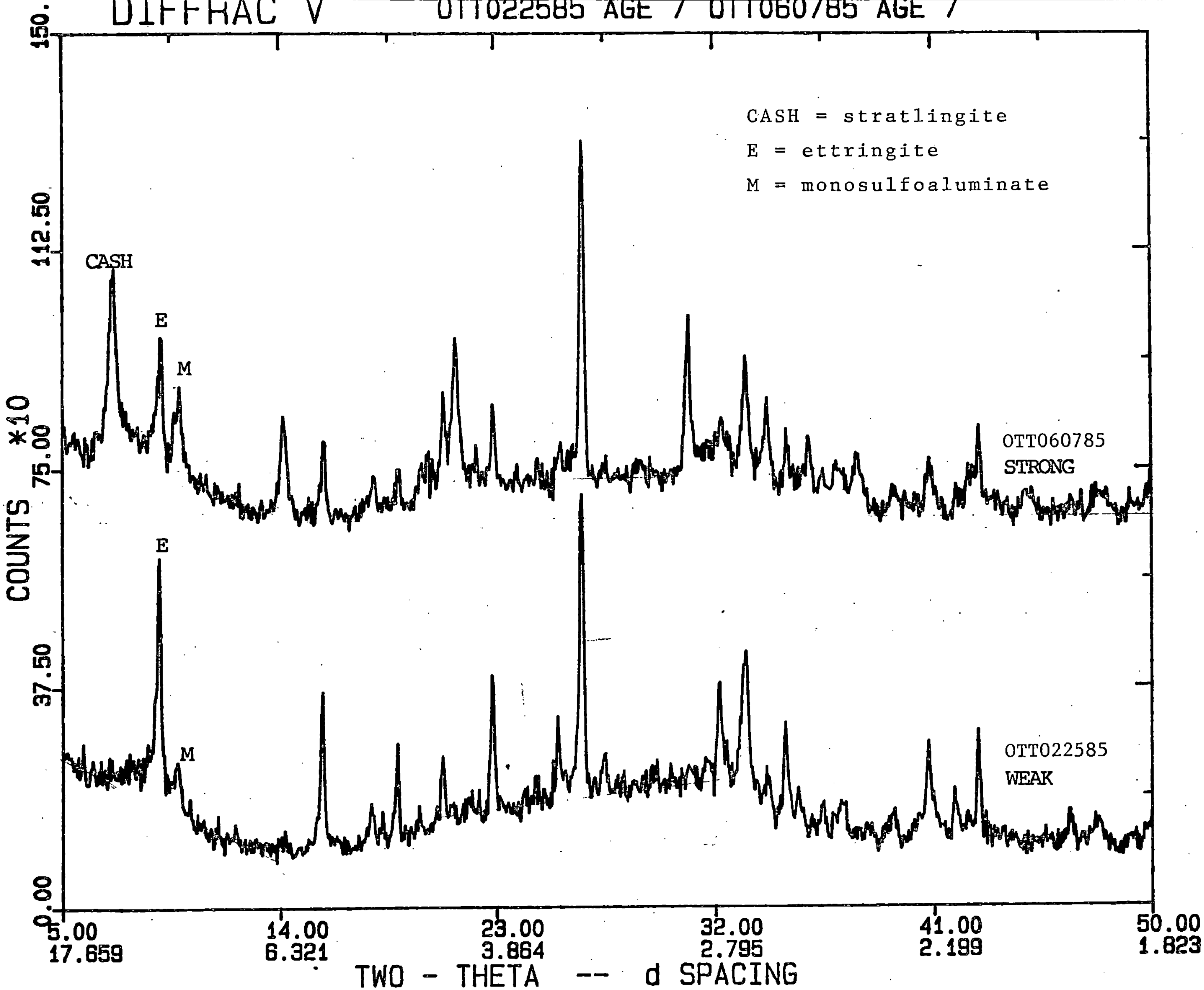

Figure 7. X-ray diffractograms of the two OGS fly ash pastes after 7 days of moist curing.

identified in the weak fly ash paste. The hydration behavior of these two fly ash pastes have been monitored using X-ray diffraction for more than two years. The results of the hydration monitoring studies are summarized in Figures 8 and 9, it is evident that the calcium-aluminate-silicate hydrate (stratlingite) formation is much quicker in the strong fly ash paste than it is in the weak fly ash paste. In fact, very little stratlingite was formed in the weak fly ash paste even after two years of moist curing. At present, it is difficult to ascertain the long-term stability of the various hydrates present in the fly ash pastes. The x-ray diffraction data indicated that some of the hydrate may be starting to decompose after two years of moist curing. However, these fly ash pastes are still being monitored so future tests results may be more definitive. The relative intensities reported in figures 8 and 9 were obtained by normalizing the peak heights of the basal planes of the various hydrates to the 3.34Å line of α-quartz. The normalization procedure was used to help correct for potential sample preparation errors and x-ray tube drift. Obviously, in making this normalization, it has been assumed that the α-quartz is not participating in any of the hydration reactions. This assumption appeared to be valid because the observed intensities of the α-quartz peaks were reproducible to within 10% (relative) over the duration of the study.

X-ray diffraction analysis of many other OGS fly ash paste specimens has also indicated that statlingite formation is directly related to compressive strength development. A plot of the net intensity of the 12.5Å stratlingite peak versus 28 day compressive strength is shown in Figure 10. The net intensities were not corrected for matrix differences between the various fly ash samples, and hence, should be regarded as only rough

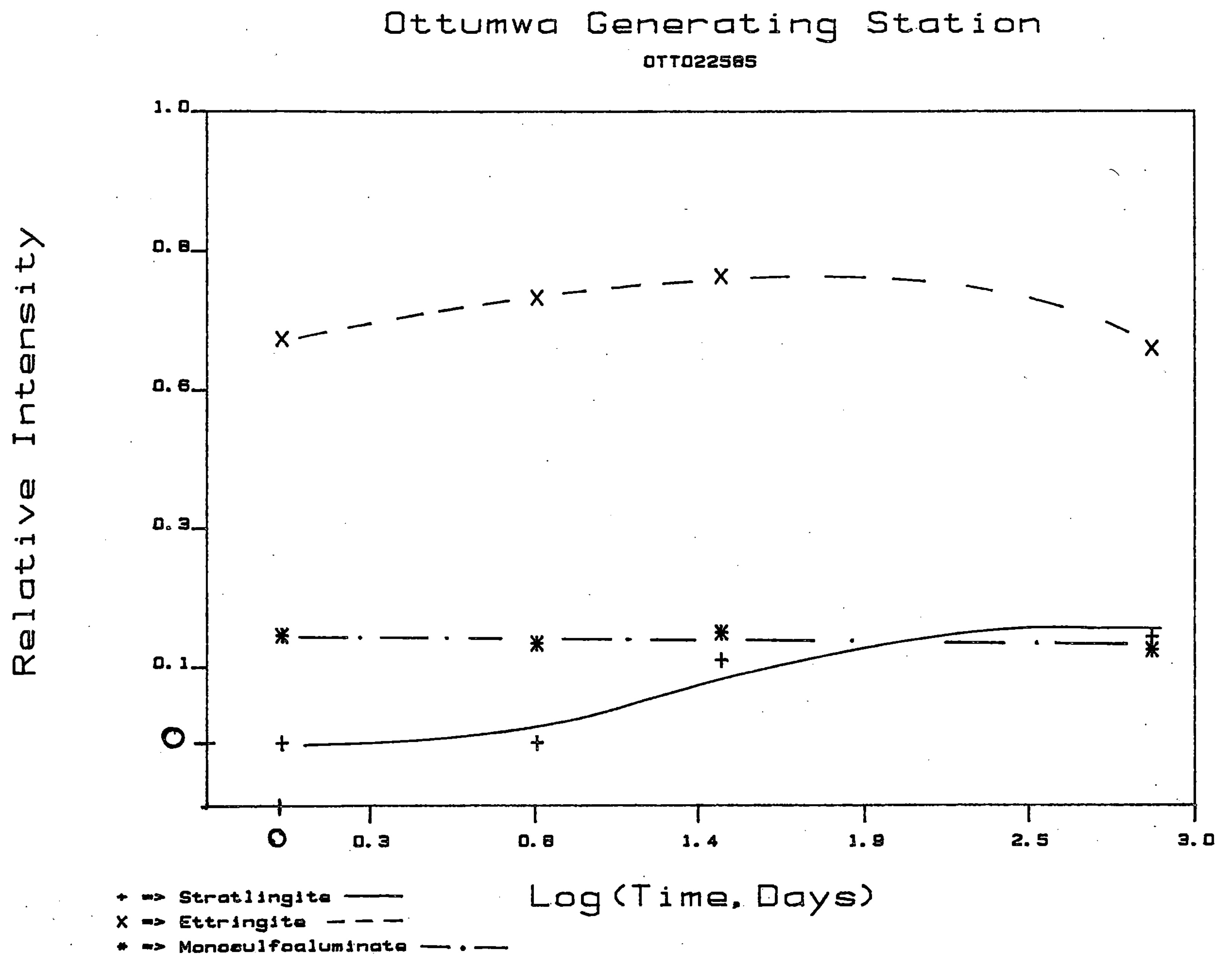

Figure 8. Relative diffracted intensity vs. log(time) for OTT022585 paste.

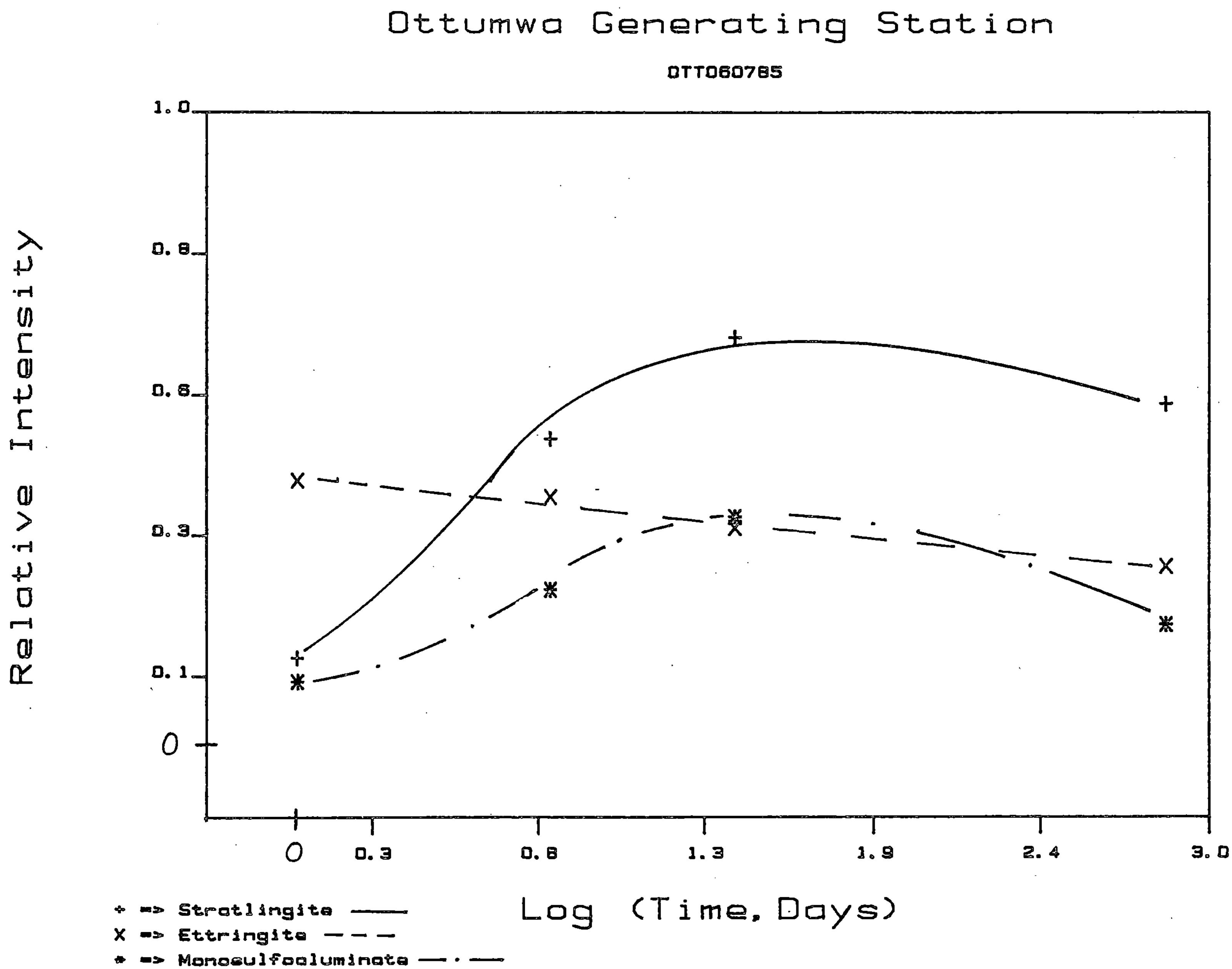

Figure 9. Relative diffracted intensity vs. log(time) for OTT060785 paste.

estimates of stratlingite concentration. However, it is evident from Figure 10, that a relationship exists between stratlingite formation and compressive strength. These findings are in agreement with those of Locher [4], whose work in the late 1950's indicated that three basic types of hydraulic binders exist in the CaO-Al_2O_3-SiO_2 ternary system. Portland cement was the first type of binder described by Locher and its cementitious reactions were dominated by calcium-silicate hydrates. High alumina cement was the second type of binder described by Locher and its cementitious reactions were dominated by calcium-aluminate hydrates. The third type of hydraulic binder described by Locher consisted of an intermediate between the two binders mentioned earlier, and its cementitious reactions were dominated by gehlenite hydrate (now referred to as stratlingite). Hence, it appears that cementitious reactions that produce very high compressive strengths in the OGS fly ash can be at least partially attributed to the formation of stratlingite.

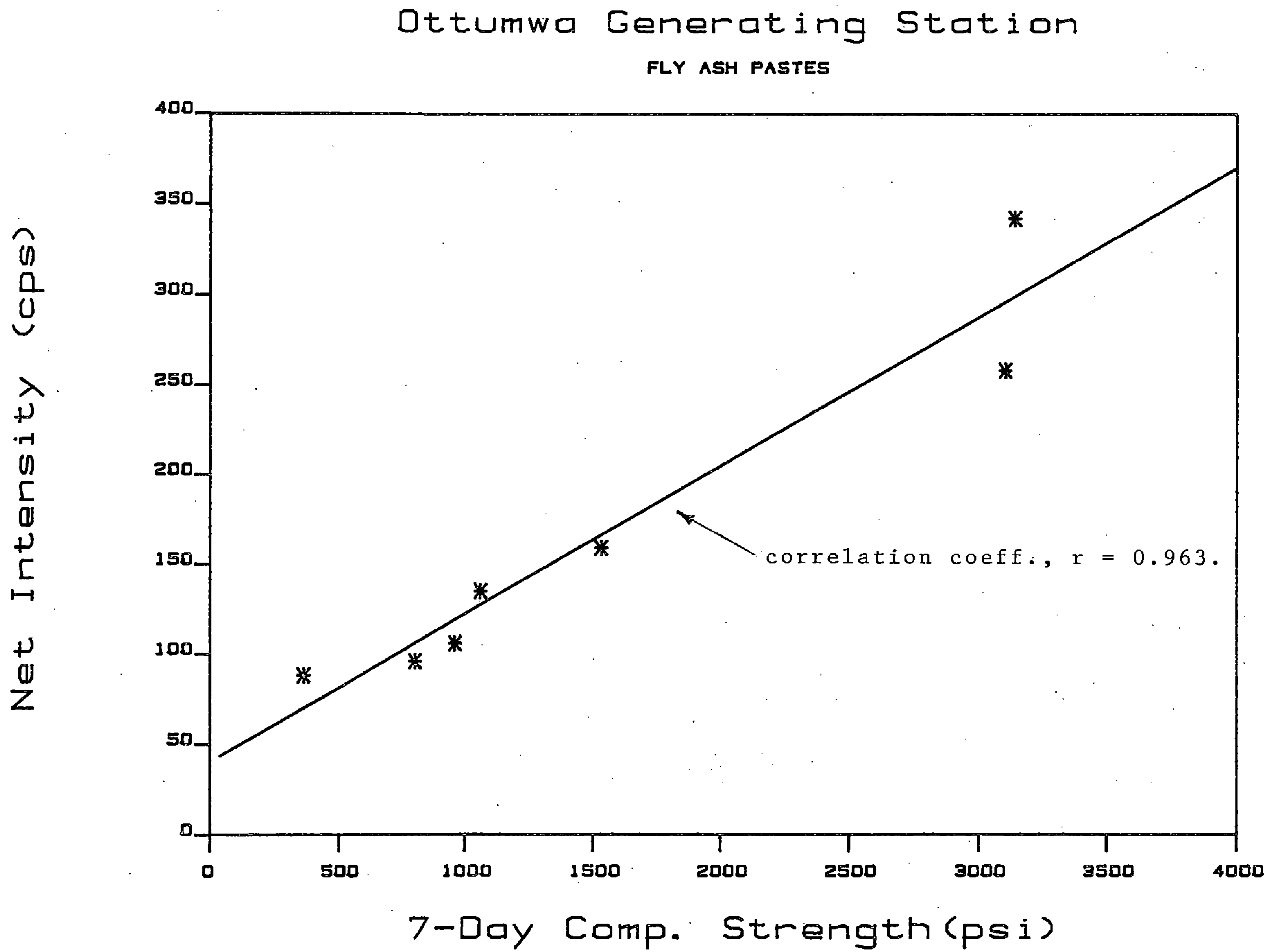

Figure 10. Net diffracted intensity vs. 7-day strength for OGS pastes.

SUMMARY AND CONCLUSIONS

The results of the second years research effort, directed towards development of a rational characterization method for Iowa fly ashes, are briefly summarized as follows.

1. The results of ASTM C 311 testing procedures obtained during 1986 were in general agreement with those obtained from earlier years. Overall, the tests show little variation in fly ash quality during the four year monitoring period.
2. The reproducibility of the fly ash paste testing scheme was found to be adequate for observing trends in the physical properties of the various fly ash sources.
3. The general physical properties of fly ash pastes were studied at various water/fly ash ratios and also under various curing conditions. In general, the fly ash pastes responded to changes in mix proportions and environmental factors in a manner similar to those normally observed for portland cement pastes.
4. Strong correlations were observed between several of the variables studied in the fly ash paste tests. The correlations observed in the second year of the project were in agreement with those reported in the first progress report. Hence, the results obtained from the first two years of fly ash paste testing were combined and subjected to further analysis. One relationship identified by the correlation study was between the 7 day and 28 day compressive strengths of the fly ash pastes. Regression analysis was used to construct a model relating 7 day strengths to 28 day strengths, the results were:

28 day strength = 1.3 x 7 day strength

The equation was constructed by using 182 observations. The coefficient of determination, R^2, for the equation was 0.87.

5. Cyclical trends were identified in the physical and chemical properties of fly ash samples obtained from Ottumwa Generating Station. The trends were tentatively linked to the power plant maintenance schedule and the sodium carbonate feed rate. These trends are still being investigated. Future data should indicate if similar trends exist at other Iowa power plants.
6. The development of compressive strength in the Ottumwa Generating Station fly ash pastes, has been tentatively linked to the formation of calcium-aluminum-silicate hydrate (stratlingite). This is, however, an oversimplification of the mineralogy that controls the strength properties of fly ash pastes because both ettringite and monosulfoaluminate have also been identified in the hydrated fly ash samples. Both ettringite and monosulfoaluminate could potentially contribute to the strength properties of fly ash pastes.

Chemical testing indicates that the presence of excessive amounts of sodium and sulfur in the bulk fly ashes tends to inhibit the development of high compressive strengths in fly ash pastes. Hence, the sodium carbonate feed rate used at the power plant can have a significant influence on the physical properties of fly ash pastes.

COMMENTS CONCERNING FUTURE RESEARCH

Research activities for the next period will be directed at development of a characterization method that will be predictive of fly ash physical properties. It has been confirmed that ASTM test methods are not adequate. Efforts will concentrate on development of simple, rapid test methods and procedures that can be utilized for engineering applications.

ACKNOWLEDGEMENTS

The cooperation and assistance of Mr. Lon Zimmerman and Midwest Fly Ash and Materials, Inc., Souix City, Iowa, in providing fly ash samples has been essential to the project. Also, the personnel at Ottumwa Generating Station, Ottumwa, Iowa, especially Mr. Rick Grubb, Mr. Mick Tauber, and Mr. Tom Opiekun, have been essential to the development of relationships between physical test data and power plant operating parameters. We thank all of these people for their continuing contributions to this research project.

REFERENCES

1. K.L. Bergeson, S. Schlorholtz, and T. Demirel, "Development of a Rational Characterization Method for Iowa Fly Ashes," Annual Progress Report 1, December 1, 1986.

2. American Society for Testing and Materials, 1985 Book of ASTM Standards, Vol 4.02 (ASTM, Philadelphia, 1985).

3. F.M. Lea, The Chemistry of Cement and Concrete, 3rd edition, Chemical Publishing Company: New York, 1971.

4. F.W. Locher, "Hydraulic Properties and Hydration of Glasses in the System CaO-Al2O3-SiO2," in the Fourth International Symposium on the Chemistry of Cement, Washington, D.C. (1960) pp. 267 - 276.

Table I, Appendix A

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62 Town Engineering
Telephone: 515-294-8752

POWER PLANT: Council Bluffs

YEAR: 1986

Total Analysis

Test	Mean	Std. Dev.	# Samples
Moisture Content	0.08	0.05	7
Loss on Ignition	0.43	0.12	7
Fineness	9.97	0.85	7
7 Day Pozz.	91.86	3.83	7
Autoclave Expan.	0.10	0.04	7
Specific Gravity	2.71	0.02	7
28 Day Pozz.	90.57	6.11	7
SiO_2	30.43	0.66	7
Al_2O_3	16.87	0.27	7
Fe_2O_3	5.33	0.15	7
SO_3	3.20	0.21	7
CaO	30.84	1.12	7
MgO	5.17	0.23	7
P_2O_5	1.34	0.20	7
K_2O	0.25	0.03	7
Na_2O	1.62	0.13	7
TiO_2	----	----	---
Avail. Alk. (equiv. Na_2O)	1.19	0.12	7

Table I, (cont.)

Iowa State University of Science and Technology Ames, Iowa 50011

Engineering Research Institute
Materials Analysis Laboratory
62 Town Engineering
Telephone: 515-294-8752

POWER PLANT: Lansing

YEAR: 1986

Total Analysis

Test	Mean	Std. Dev.	# Samples
Moisture Content	0.05	0.02	8
Loss on Ignition	0.51	0.21	8
Fineness	11.46	1.95	8
7 Day Pozz.	89.13	2.71	8
Autoclave Expan.	0.09	0.05	8
Specific Gravity	2.78	0.04	8
28 Day Pozz.	94.63	5.24	8
SiO_2	30.39	0.81	8
Al_2O_3	16.64	0.87	8
Fe_2O_3	5.95	0.35	8
SO_3	3.57	0.44	8
CaO	29.30	1.68	8
MgO	5.77	0.64	8
P_2O_5	1.00	0.23	8
K_2O	0.26	0.05	8
Na_2O	1.76	0.31	8
TiO_2	----	----	--
Avail. Alk. (equiv. Na_2O)	1.29	0.21	8

Table I, (cont.)

Iowa State University of Science and Technology Ames, Iowa 50011

Engineering Research Institute
Materials Analysis Laboratory
62 Town Engineering
Telephone: 515-294-8752

POWER PLANT: Neal 4

YEAR: 1986

Test	Mean	Std. Dev.	# Samples
	Total Analysis		
Moisture Content	0.05	0.10	9
Loss on Ignition	0.35	0.08	9
Fineness	11.81	0.66	9
7 Day Pozz.	86.89	3.07	9
Autoclave Expan.	0.06	0.03	9
Specific Gravity	2.68	0.04	9
28 Day Pozz.	91.89	5.45	9
SiO_2	31.68	0.93	9
Al_2O_3	16.26	0.97	9
Fe_2O_3	6.03	0.23	9
SO_3	3.16	0.43	9
CaO	27.12	0.85	9
MgO	5.51	0.43	9
P_2O_5	1.10	0.53	9
K_2O	0.26	0.05	9
Na_2O	2.67	0.10	9
TiO_2	----	----	--
Avail. Alk. (equiv. Na_2O)	1.62	0.10	9

Table I, (cont.)

Iowa State University of Science and Technology Ames, Iowa 50011

Engineering Research Institute
Materials Analysis Laboratory
62 Town Engineering
Telephone: 515-294-8752

POWER PLANT: Ottumwa

YEAR: 1986

Total Analysis

Test	Mean	Std. Dev.	# Samples
Moisture Content	0.04	0.02	16
Loss on Ignition	0.30	0.07	16
Fineness	9.55	0.67	16
7 Day Pozz.	93.44	5.08	16
Autoclave Expan.	0.02	0.03	16
Specific Gravity	2.68	0.02	16
28 Day Pozz.	98.25	5.53	16
SiO_2	30.97	1.05	16
Al_2O_3	18.61	0.34	16
Fe_2O_3	5.97	0.21	16
SO_3	2.53	0.25	16
CaO	25.61	0.66	16
MgO	4.70	0.20	16
P_2O_5	1.65	0.18	16
K_2O	0.36	0.03	16
Na_2O	2.01	0.23	16
TiO_2	----	----	--
Avail. Alk. (equiv. Na_2O)	1.31	0.19	16

Table II, Appendix A

Summary of ASTM C 311 physical testing statistics for 1986

Test	Ottumwa n = 74 X̄	S	R	Council Bluffs n= 32 X̄	S	R
Moisture Content	0.03	0.03	0.13	0.07	0.06	0.19
Loss on Ignition	0.31	0.06	0.28	0.42	0.17	0.71
Fineness	9.47	0.93	4.70	9.96	1.08	4.2
7-day Pozzolan	93.5	6.8	31.0	87.8	6.3	27.0
Autoclave Exp.	0.03	0.03	0.11	0.09	0.03	0.11
Specific Gravity	2.68	0.02	0.12	2.71	0.02	0.11

Test	Lansing n = 19 X̄	S	R	Neal 4 n= 31 X̄	S	R
Moisture Content	0.03	0.03	0.09	0.05	0.03	0.15
Loss on Ignition	0.52	0.19	0.75	0.34	0.06	0.23
Fineness	11.56	2.20	7.70	11.85	0.86	3.4
7-day Pozzolan	85.7	5.7	22.0	87.6	6.1	23.0
Autoclave Exp.	0.08	0.04	0.13	0.08	0.04	0.11
Specific Gravity	2.79	0.02	0.05	2.70	0.02	0.06

1983–86 MOISTURE CONTENT MONITORING

OTTUMWA FLY ASH

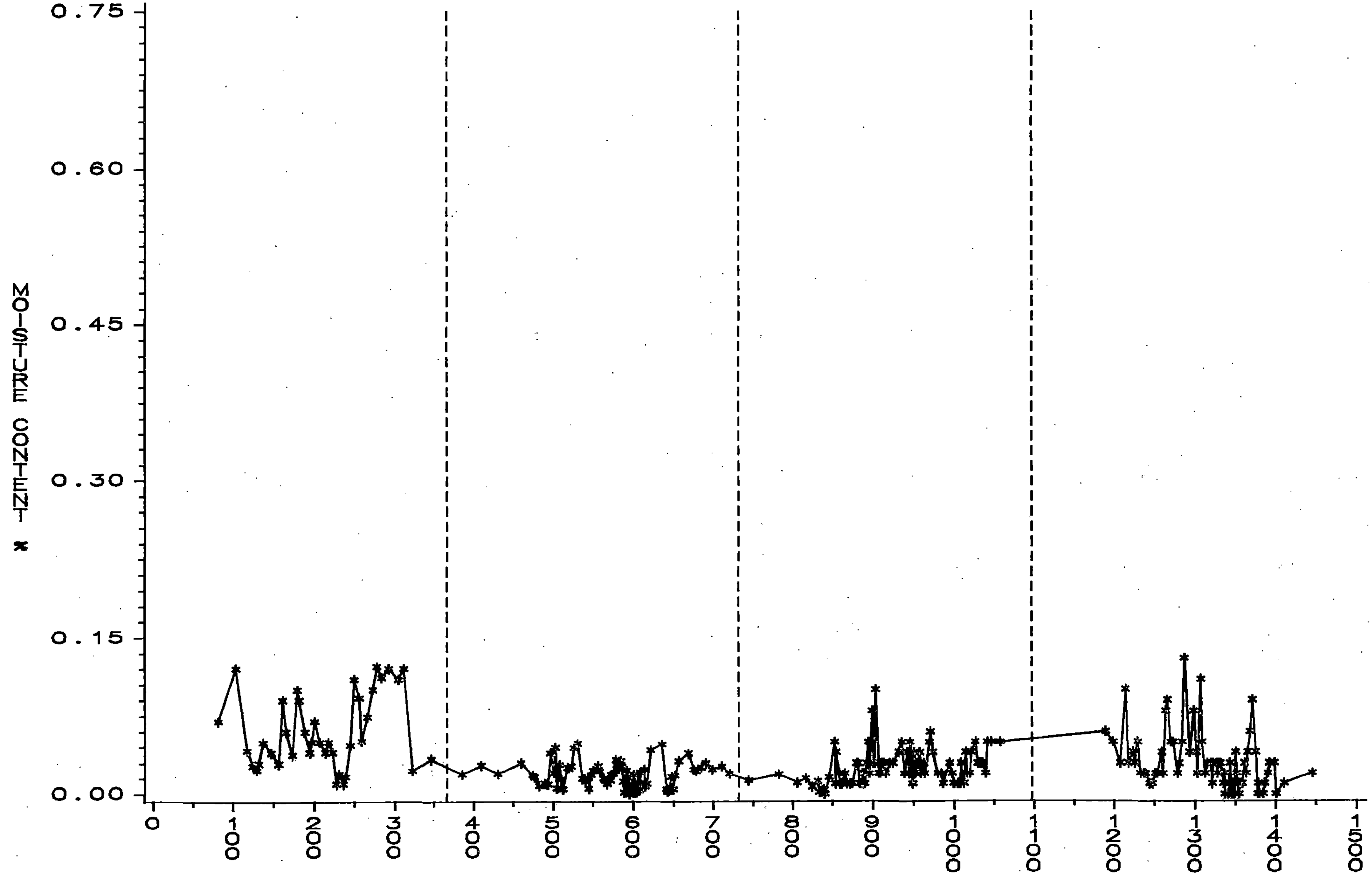

Figure 1, Appendix A

1983-86 LOSS ON IGNITION MONITORING

OTTUMWA FLY ASH

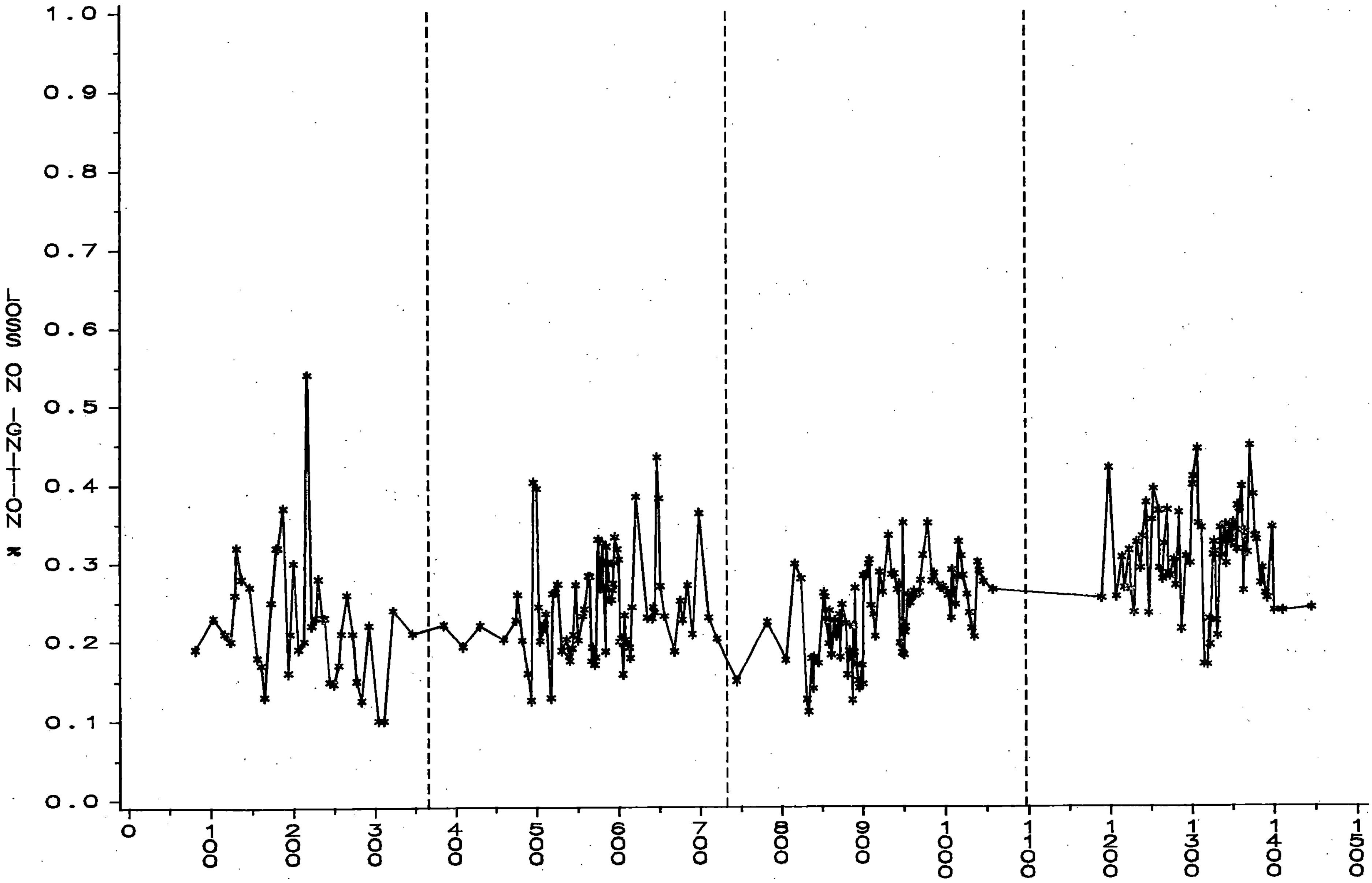

Figure 2, Appendix A

1983–86 FINENESS MONITORING

OTTUMWA FLY ASH

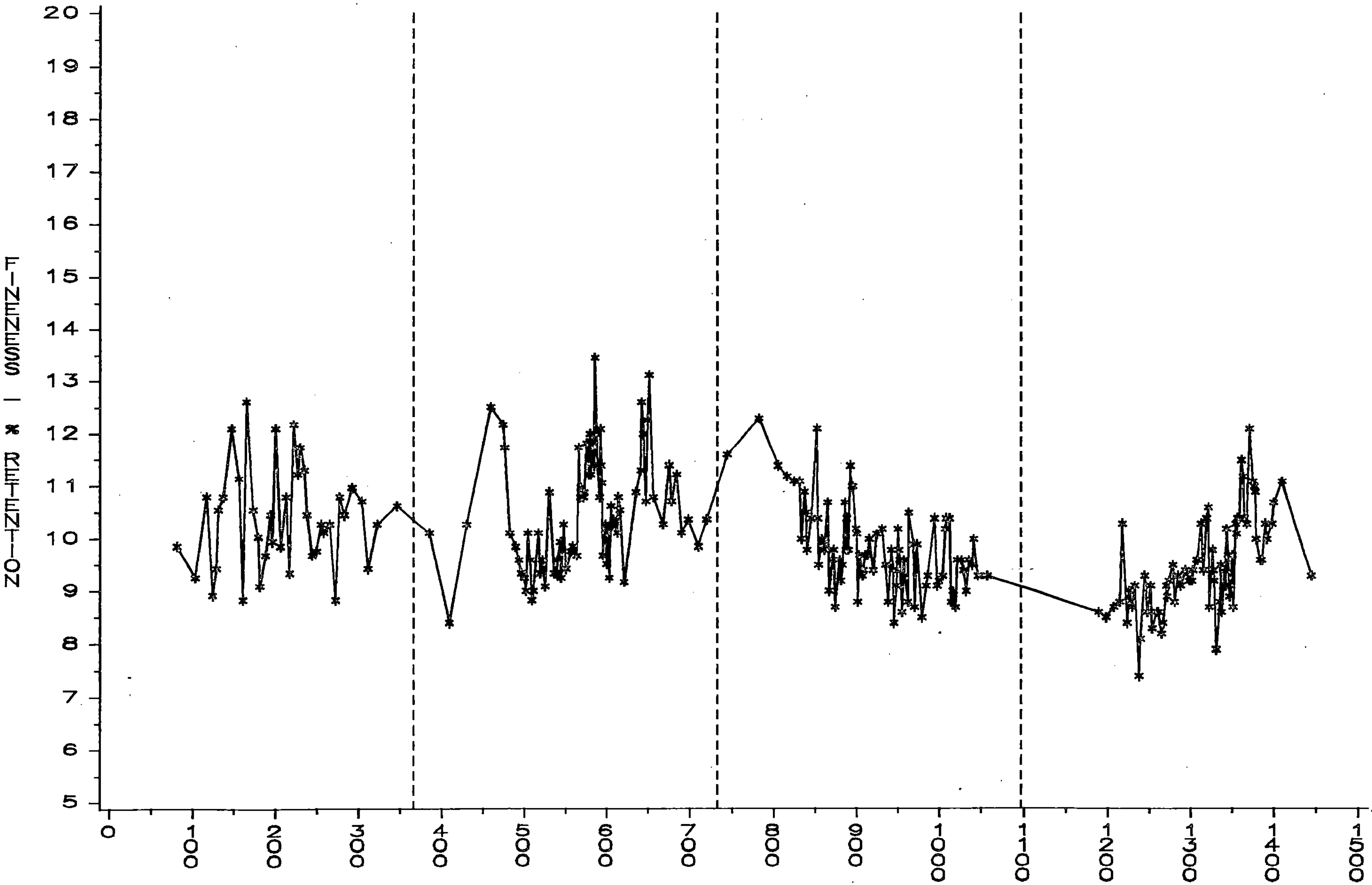

Figure 3, Appendix A

1983-86 7-DAY CEMENT POZZ MONITORING

OTTUMWA FLY ASH

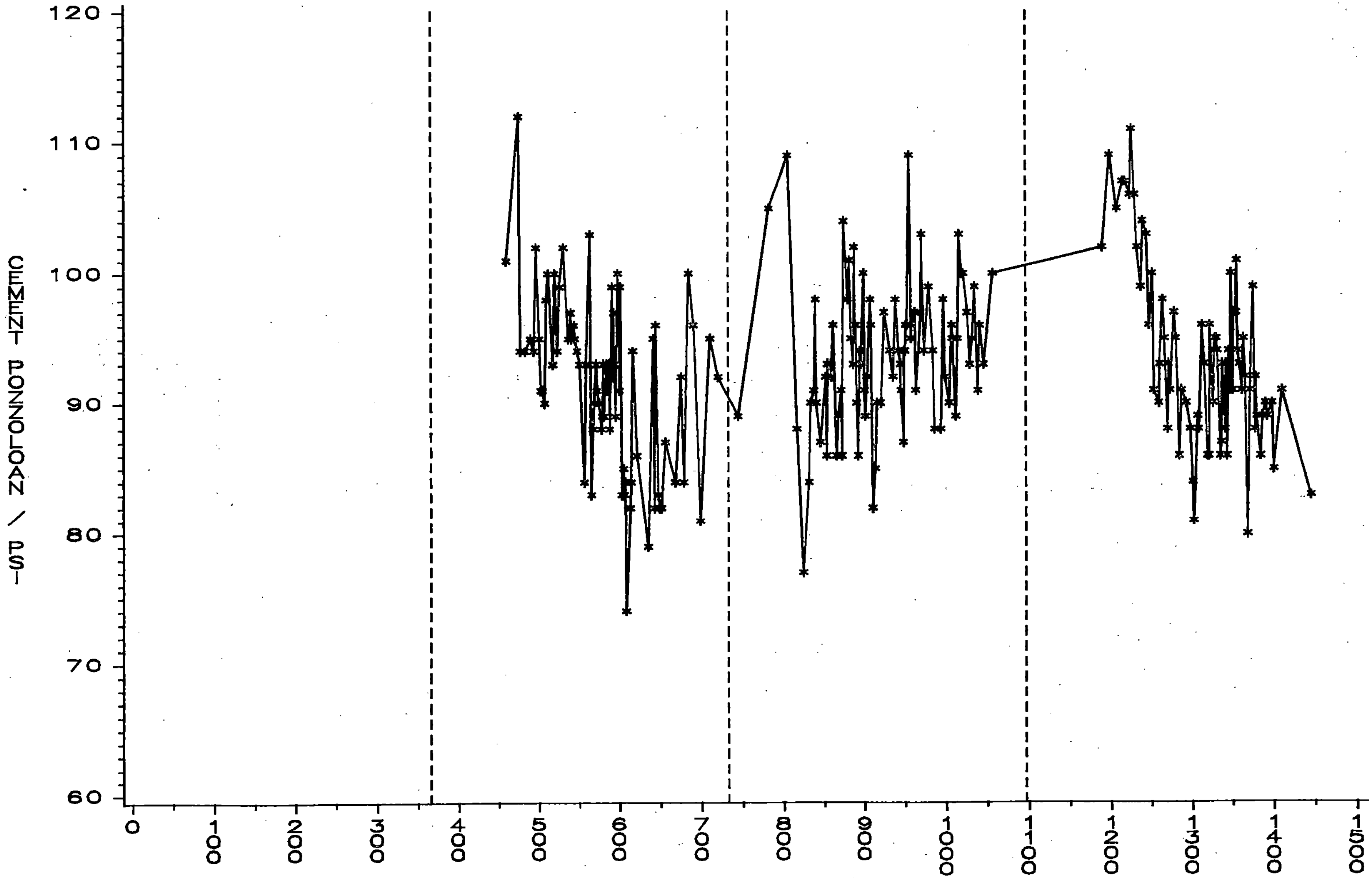

Figure 4, Appendix A

1983–86 AUTOCLAVE EXPANSION MONITORING

OTTUMWA FLY ASH

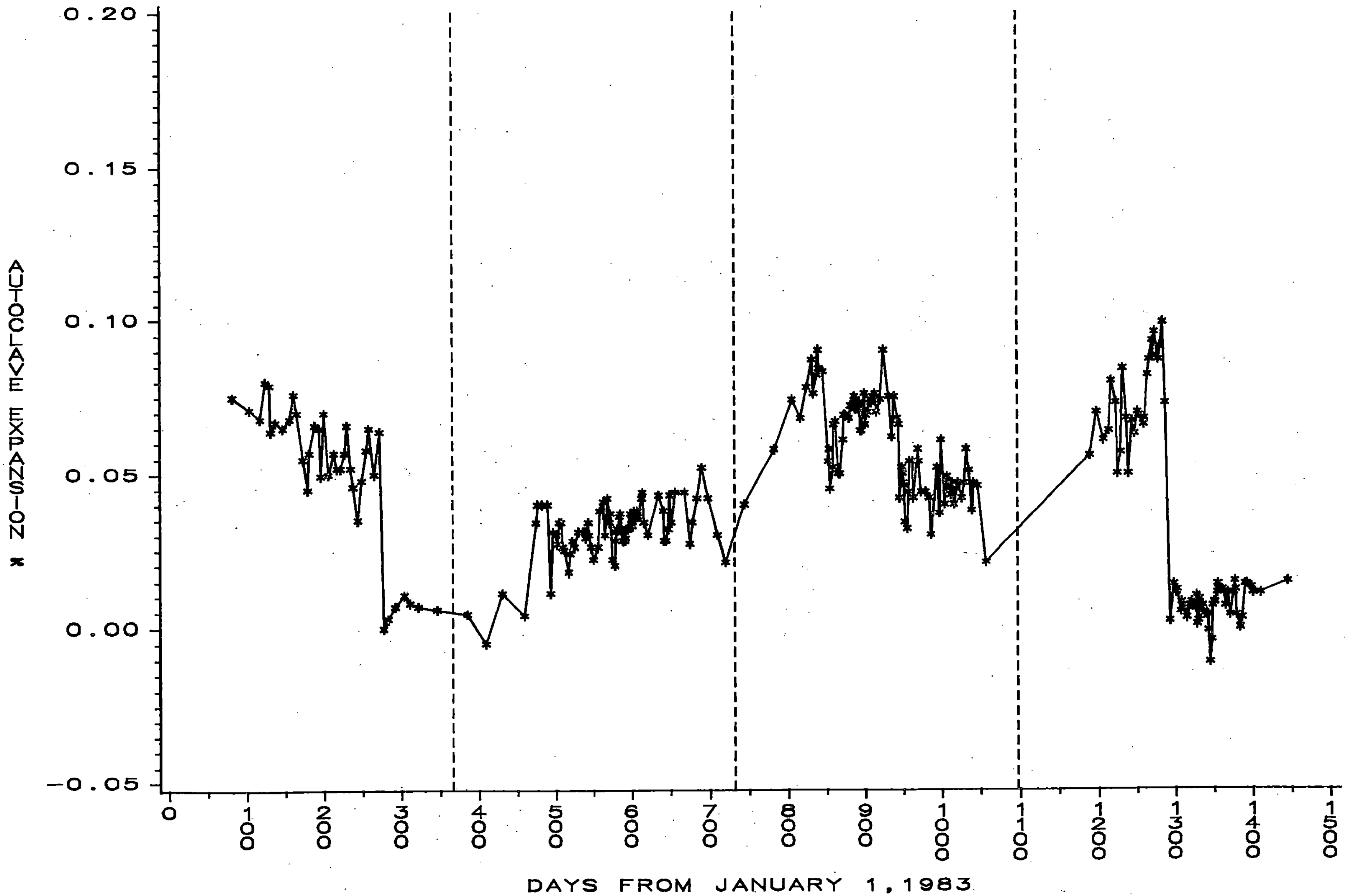

Figure 5, Appendix A

1983–86 SPECIFIC GRAVITY MONITORING

OTTUMWA FLY ASH

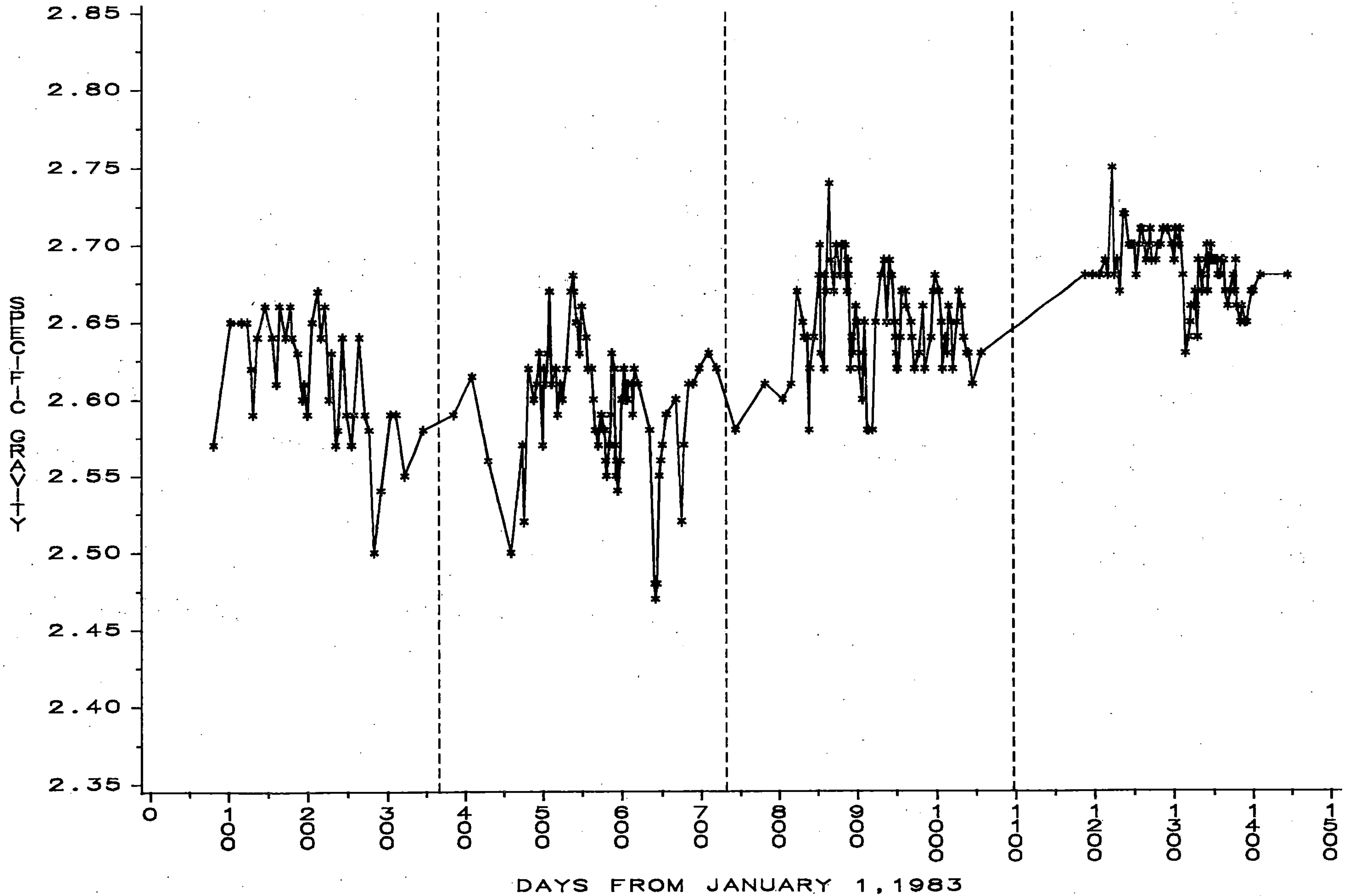

Figure 6, Appendix A

1983–86 MOISTURE CONTENT MONITORING

COUNCIL BLUFFS FLY ASH

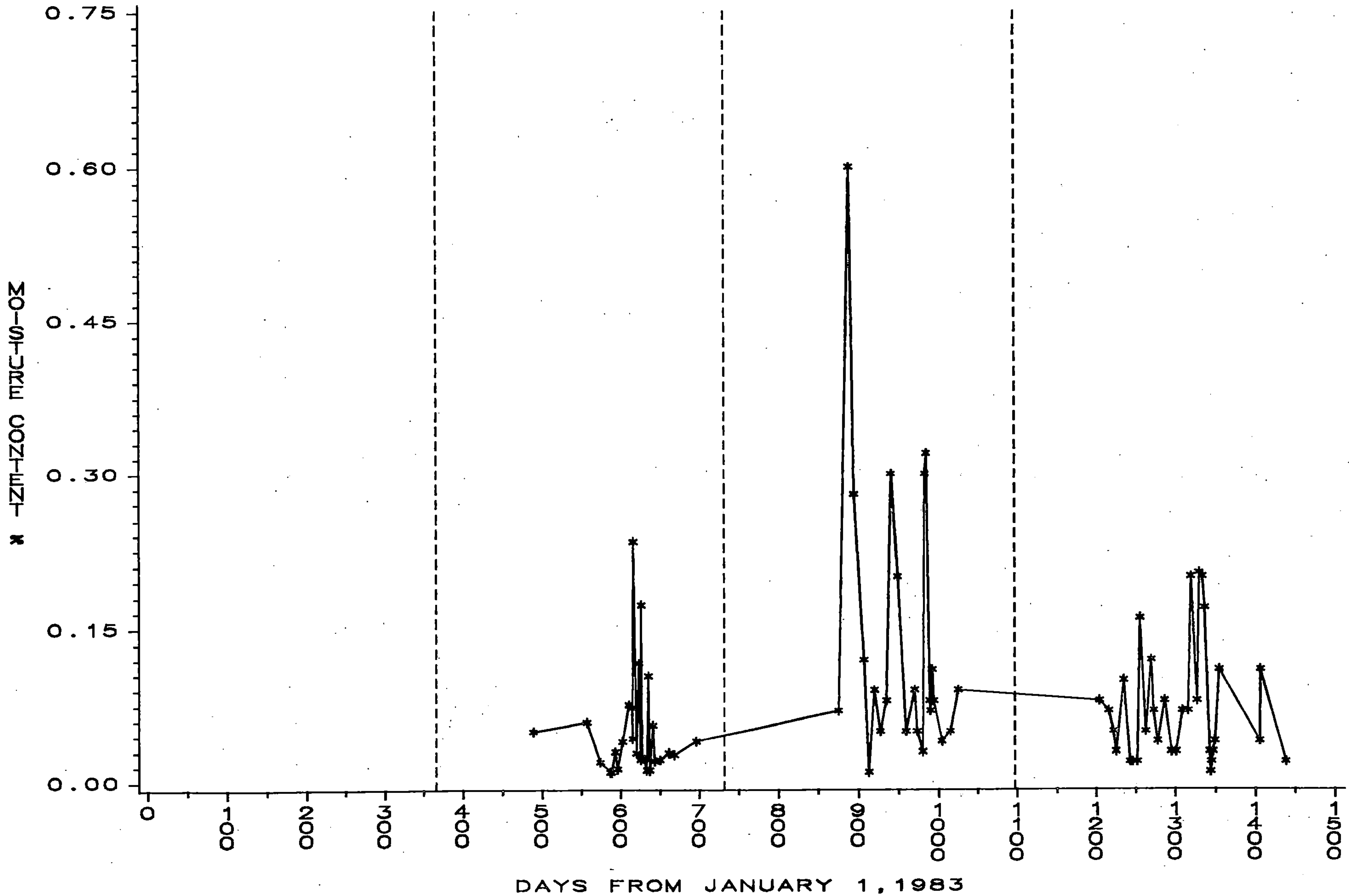

Figure 7, Appendix A

1983–86 LOSS ON IGNITION MONITORING

COUNCIL BLUFFS FLY ASH

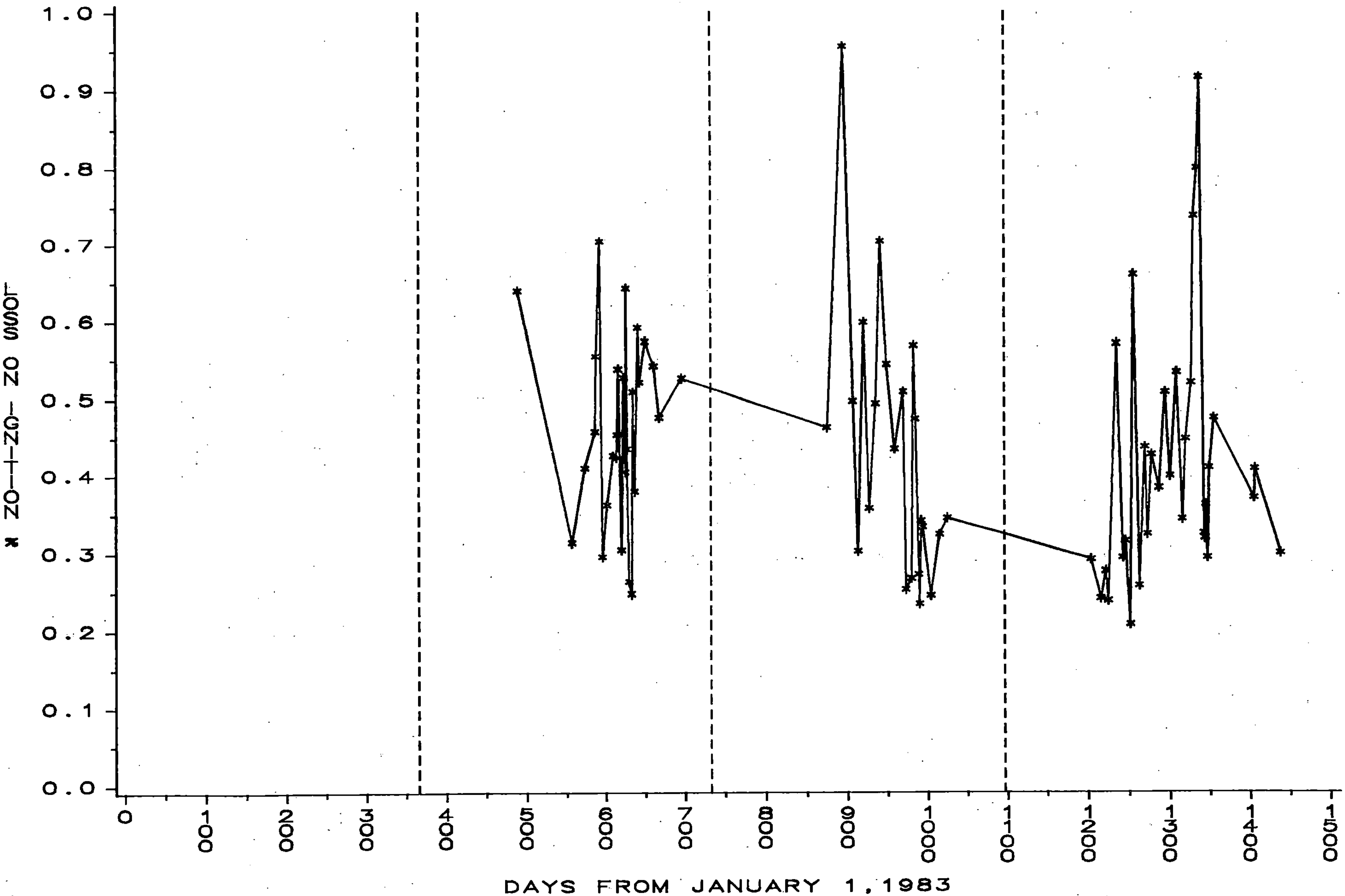

Figure 8, Appendix A

1983–86 FINENESS MONITORING

COUNCIL BLUFFS FLY ASH

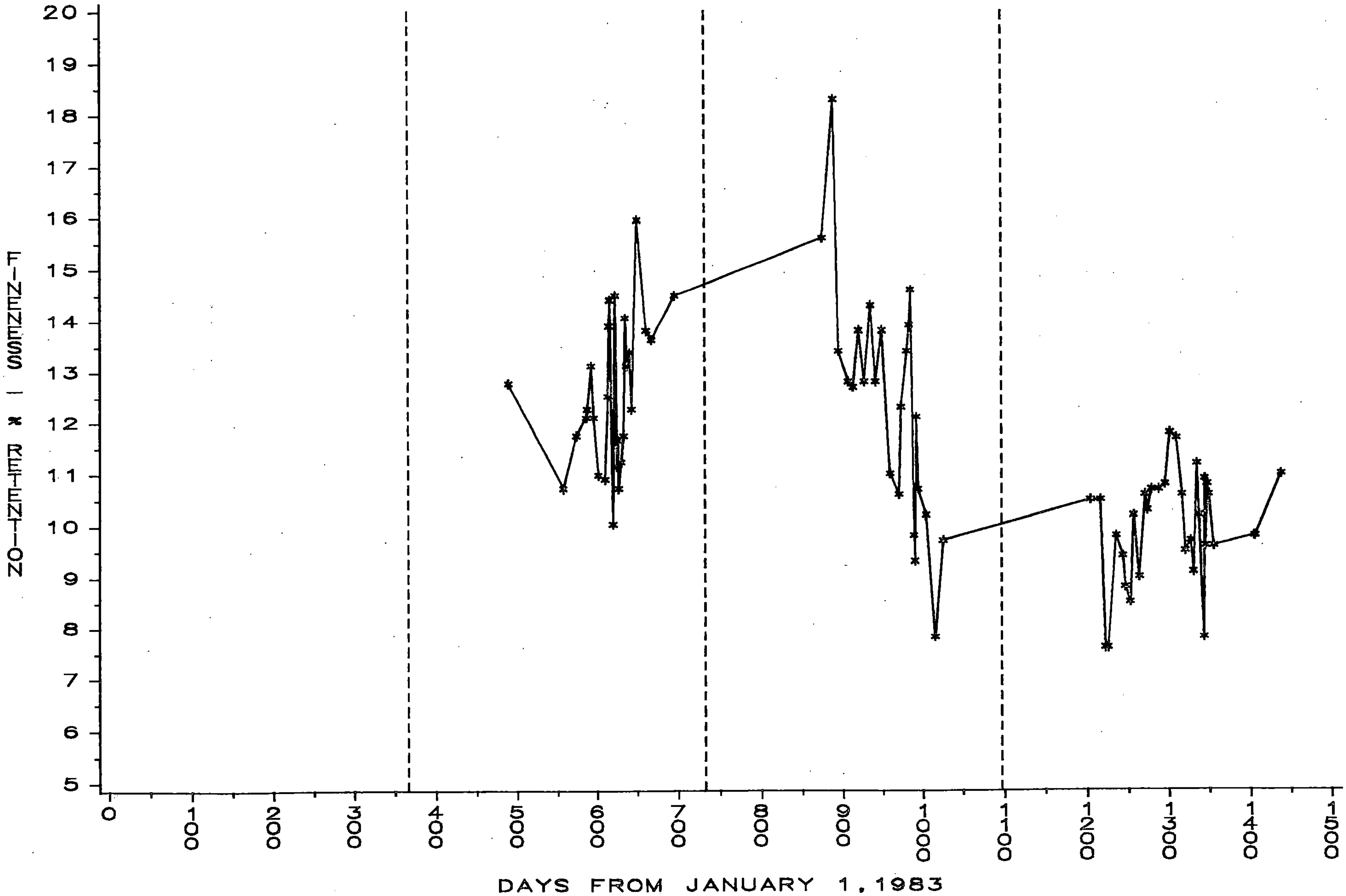

Figure 9, Appendix A

1983-86 7-DAY CEMENT POZZ MONITORING

COUNCIL BLUFFS FLY ASH

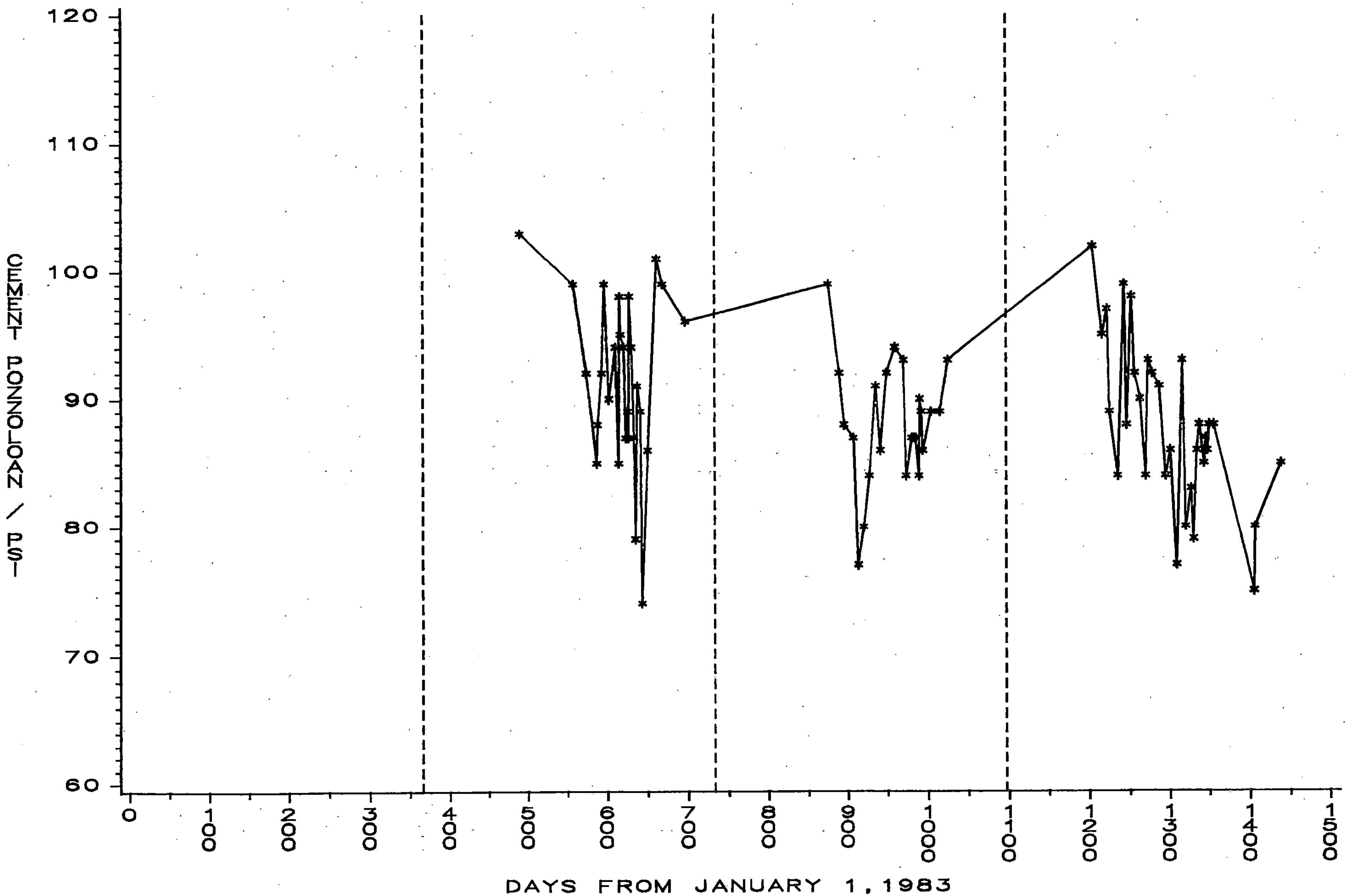

Figure 10, Appendix A

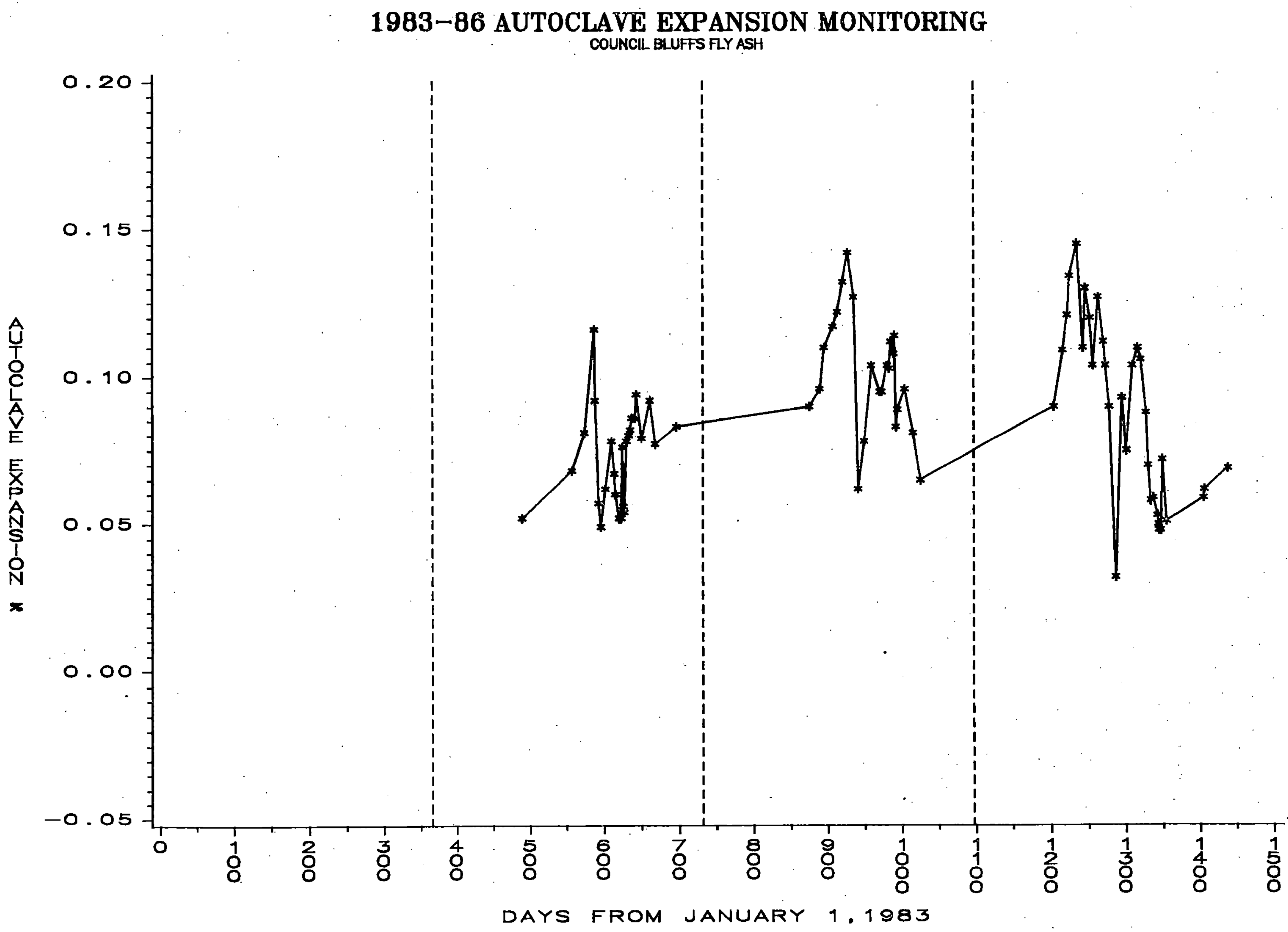

Figure 11, Appendix A

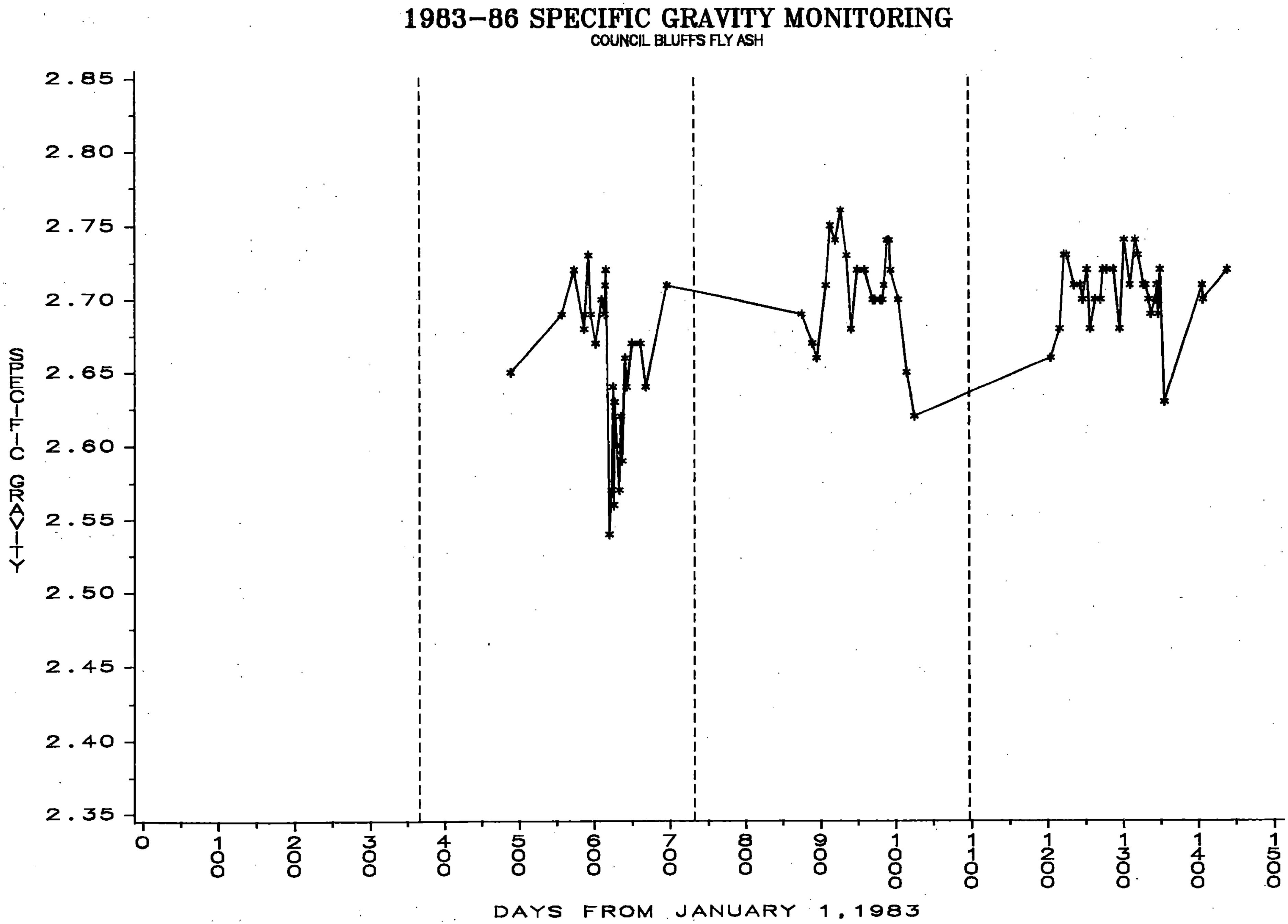

Figure 12, Appendix A

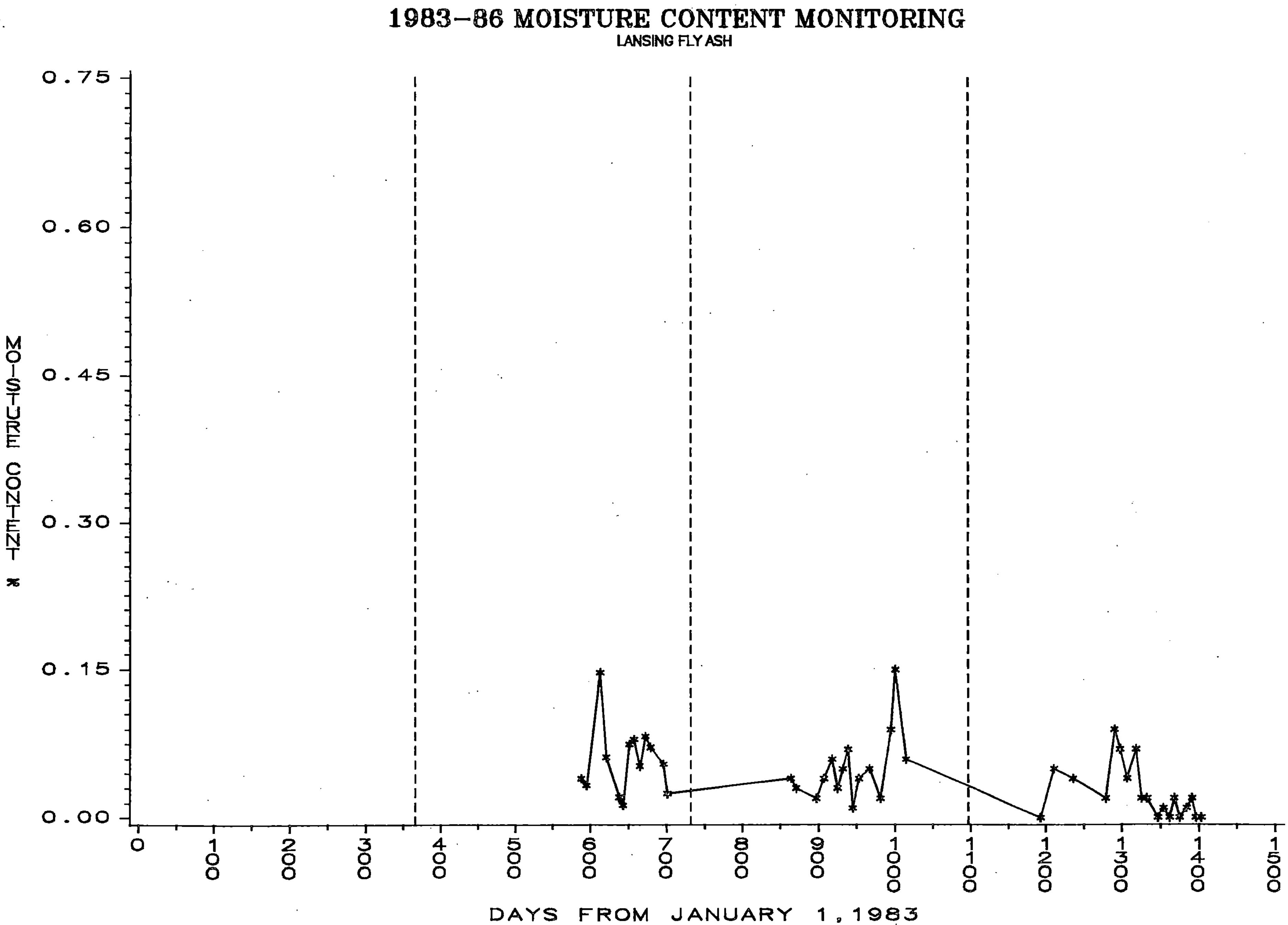

Figure 13, Appendix A

1983–86 LOSS ON IGNITION MONITORING

LANSING FLY ASH

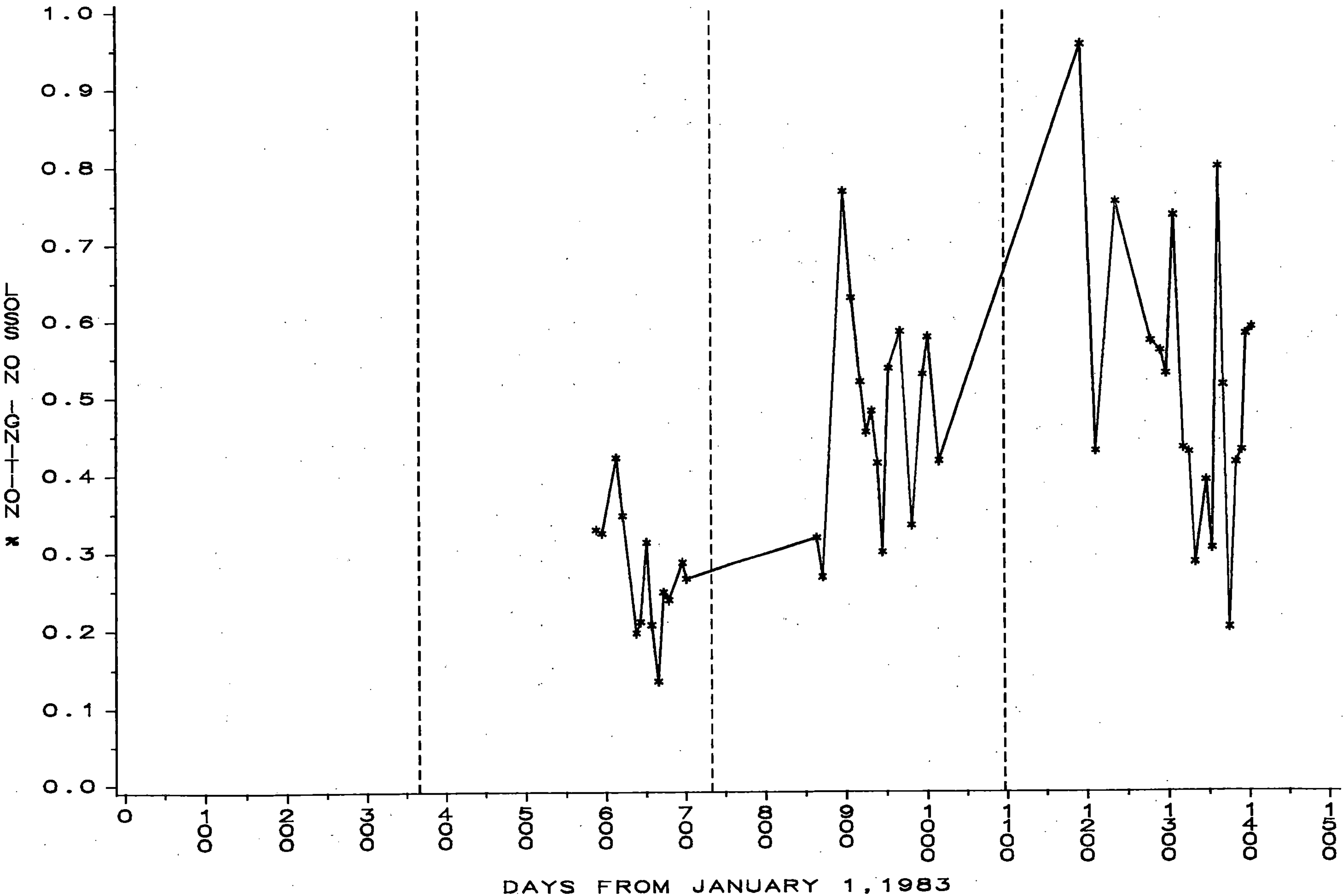

Figure 14, Appendix A

1983–86 FINENESS MONITORING

LANSING FLY ASH

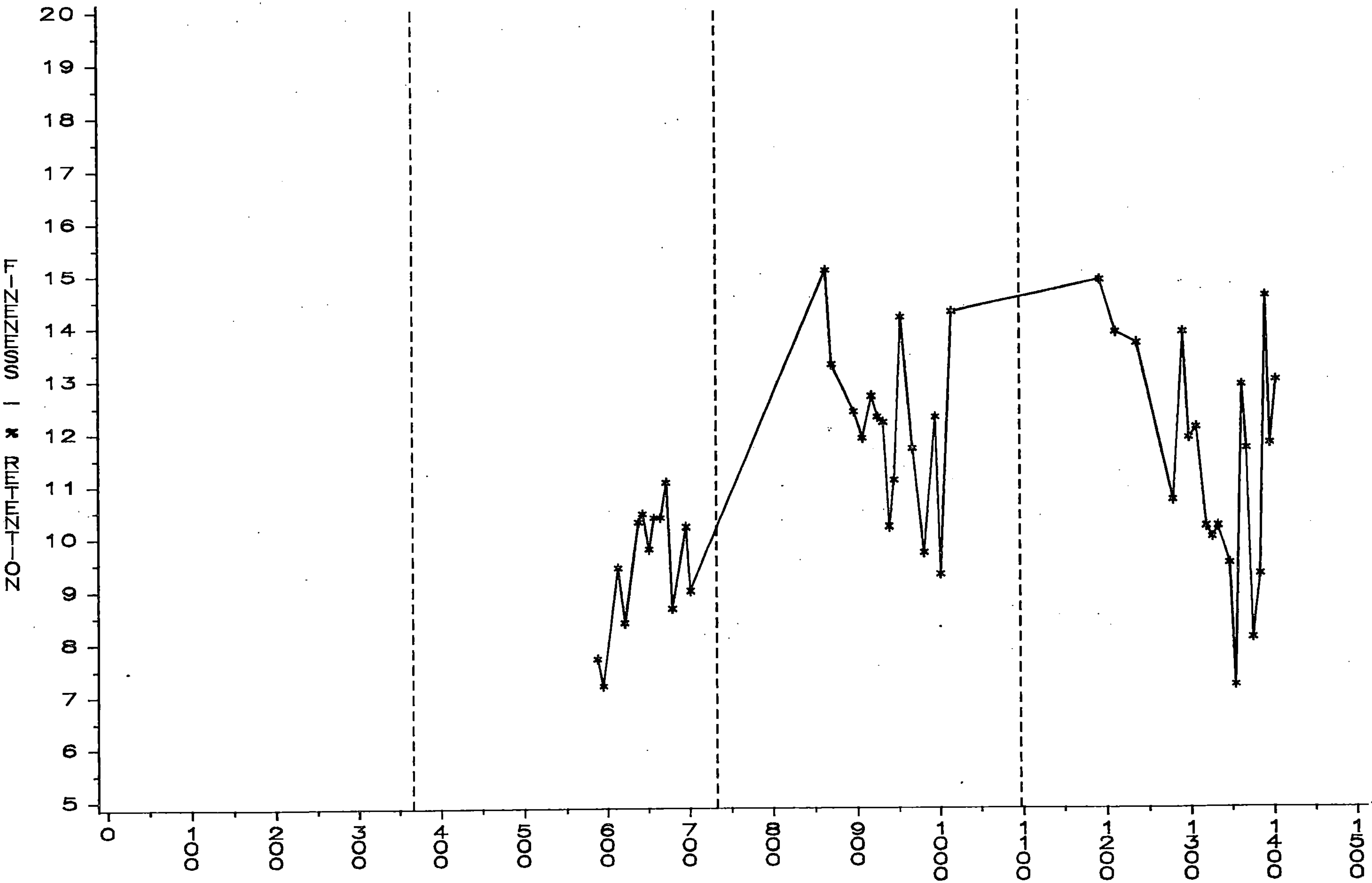

Figure 15, Appendix A

1983-86 7-DAY CEMENT POZZ MONITORING

LANSING FLY ASH

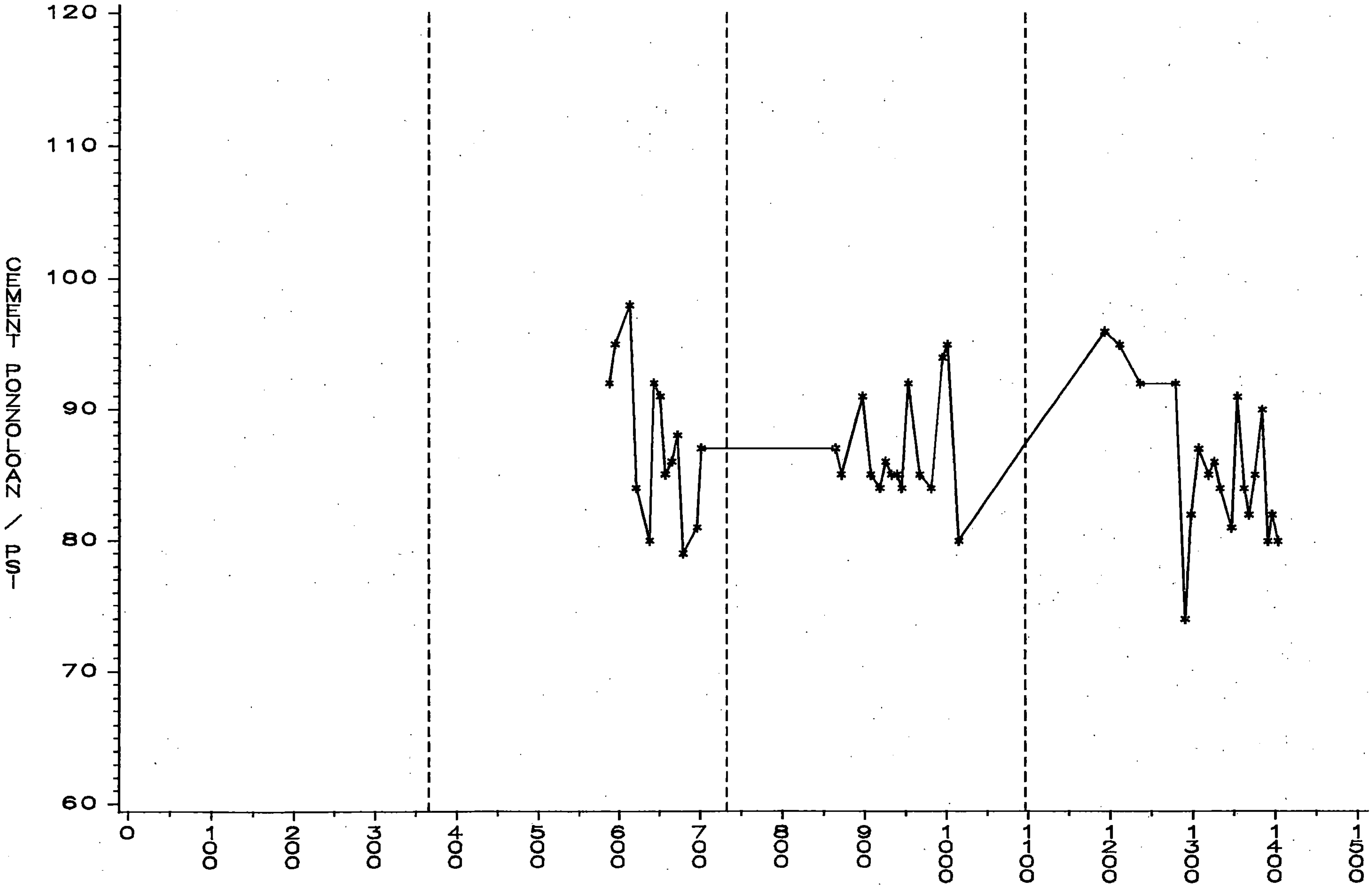

Figure 16, Appendix A

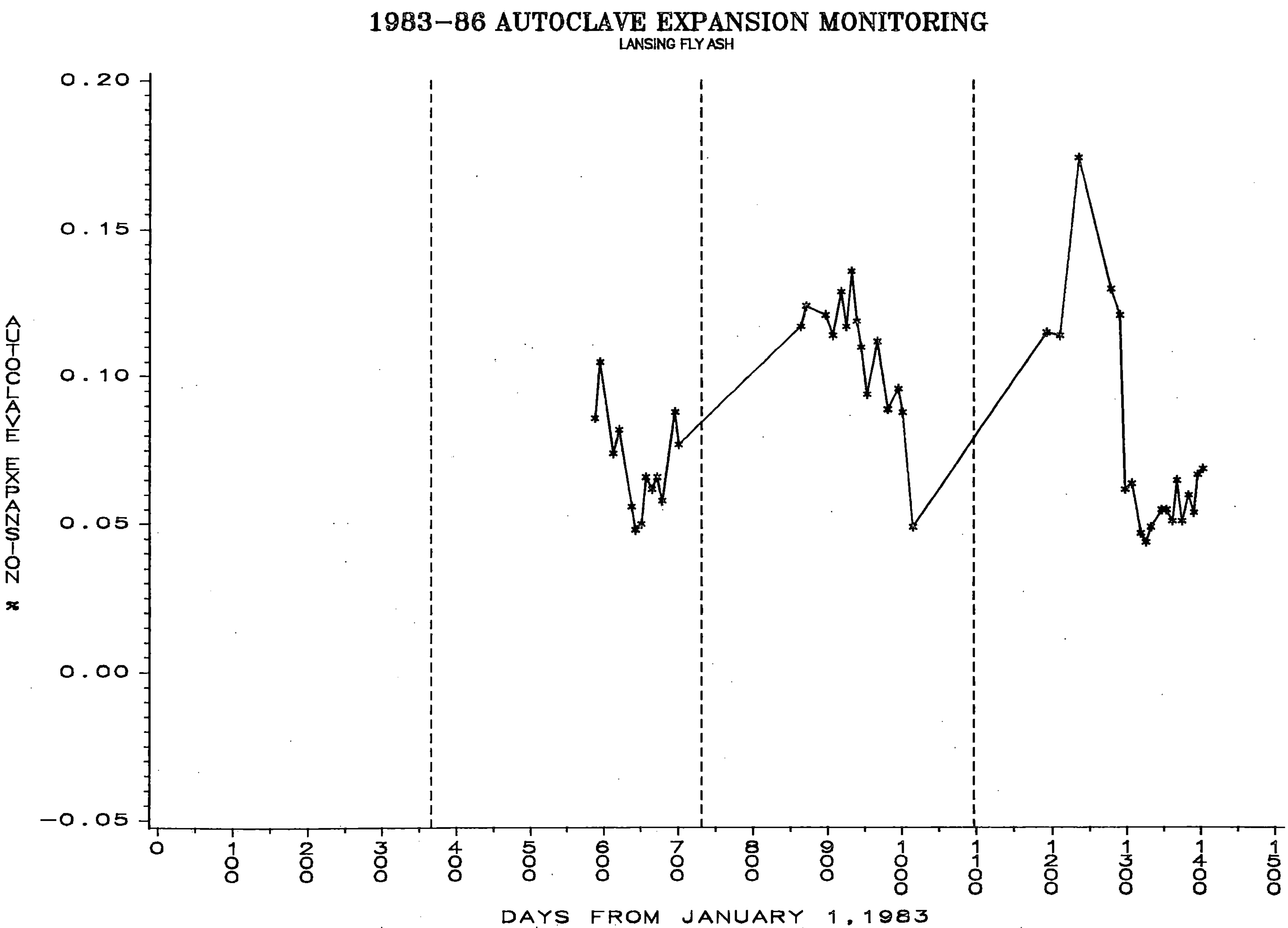

Figure 17, Appendix A

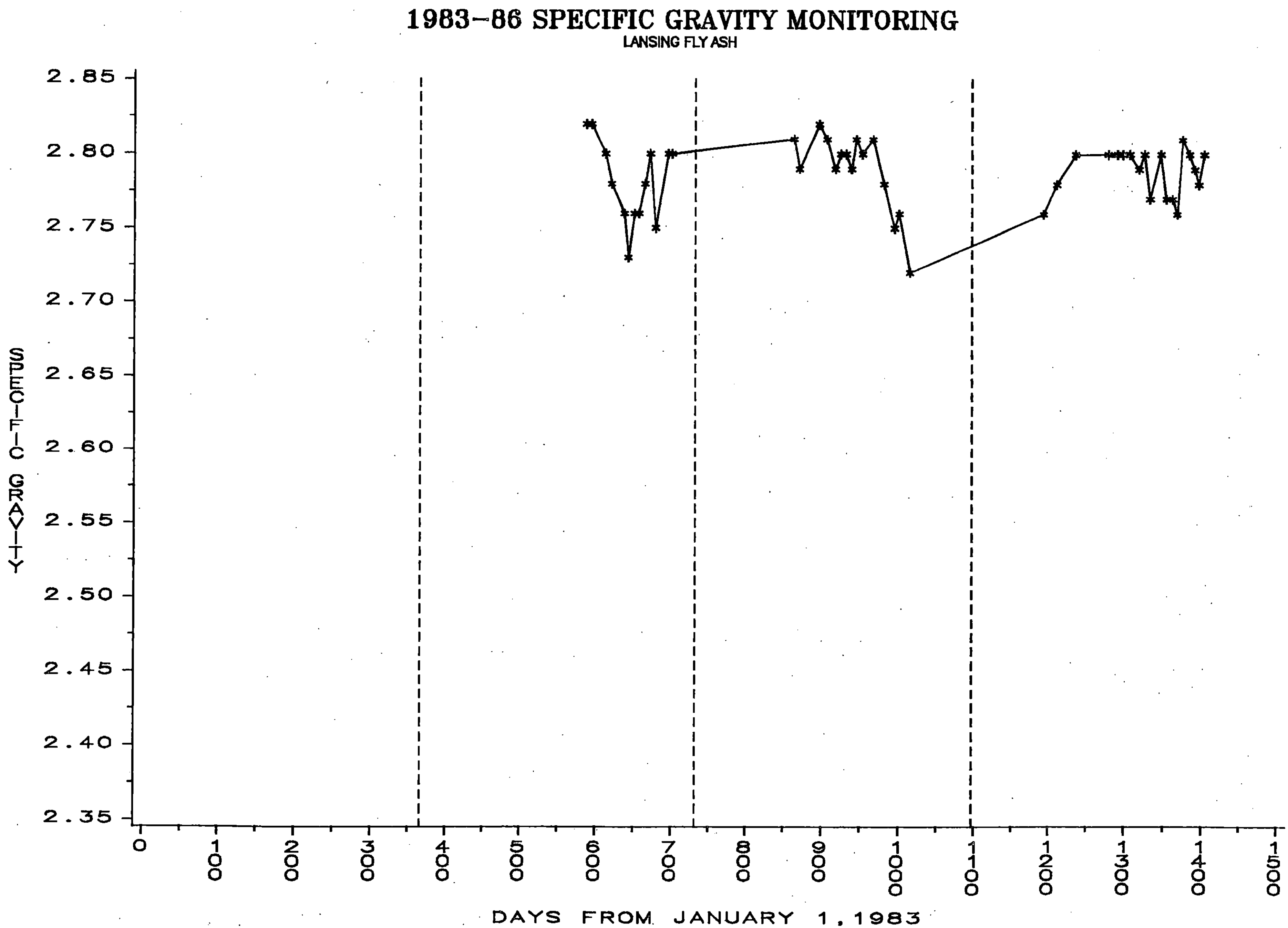

Figure 18, Appendix A

1983–86 MOISTURE CONTENT MONITORING

PORT NEAL #4 FLY ASH

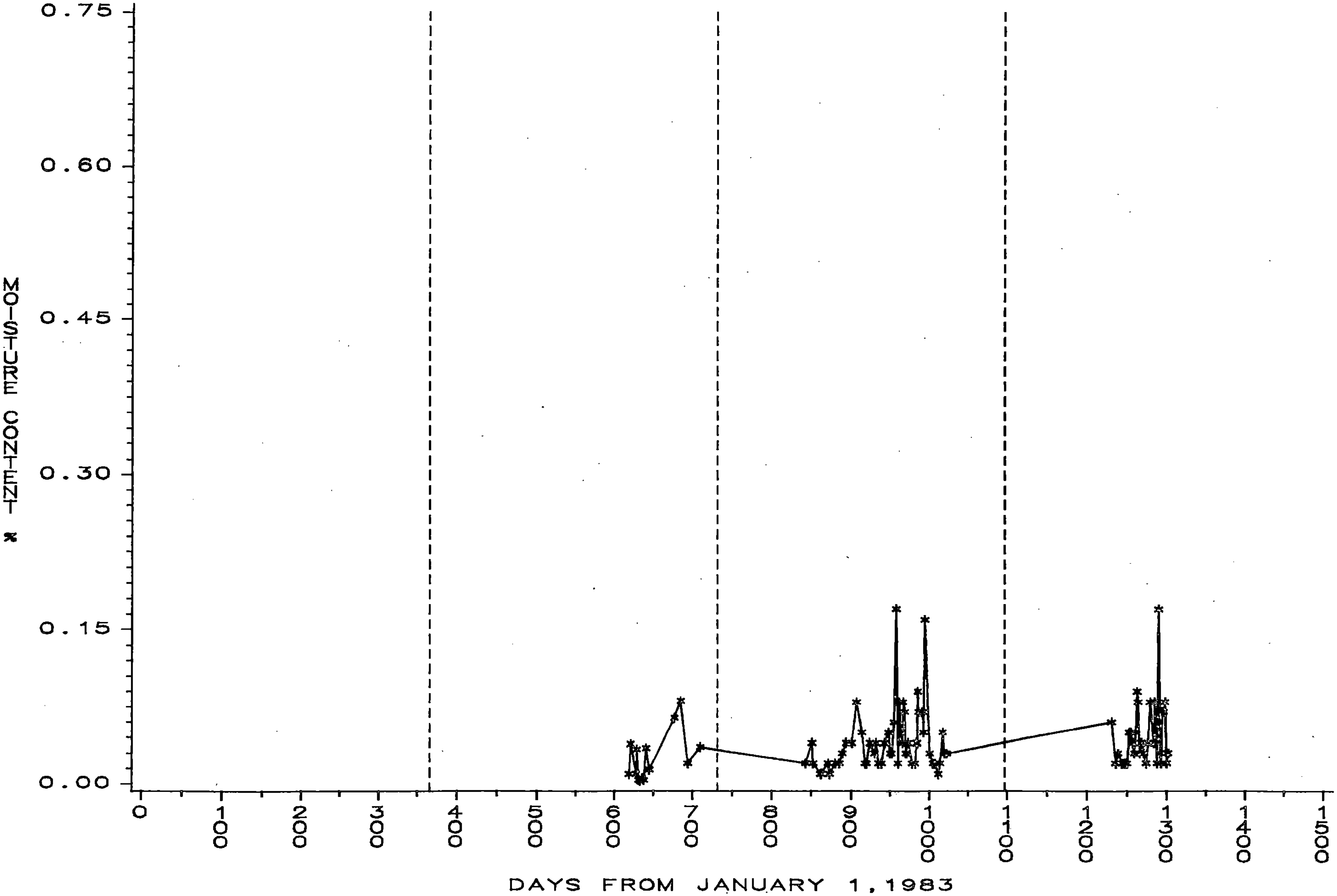

Figure 19, Appendix A

1983–86 LOSS ON IGNITION MONITORING

PORT NEAL #4 FLY ASH

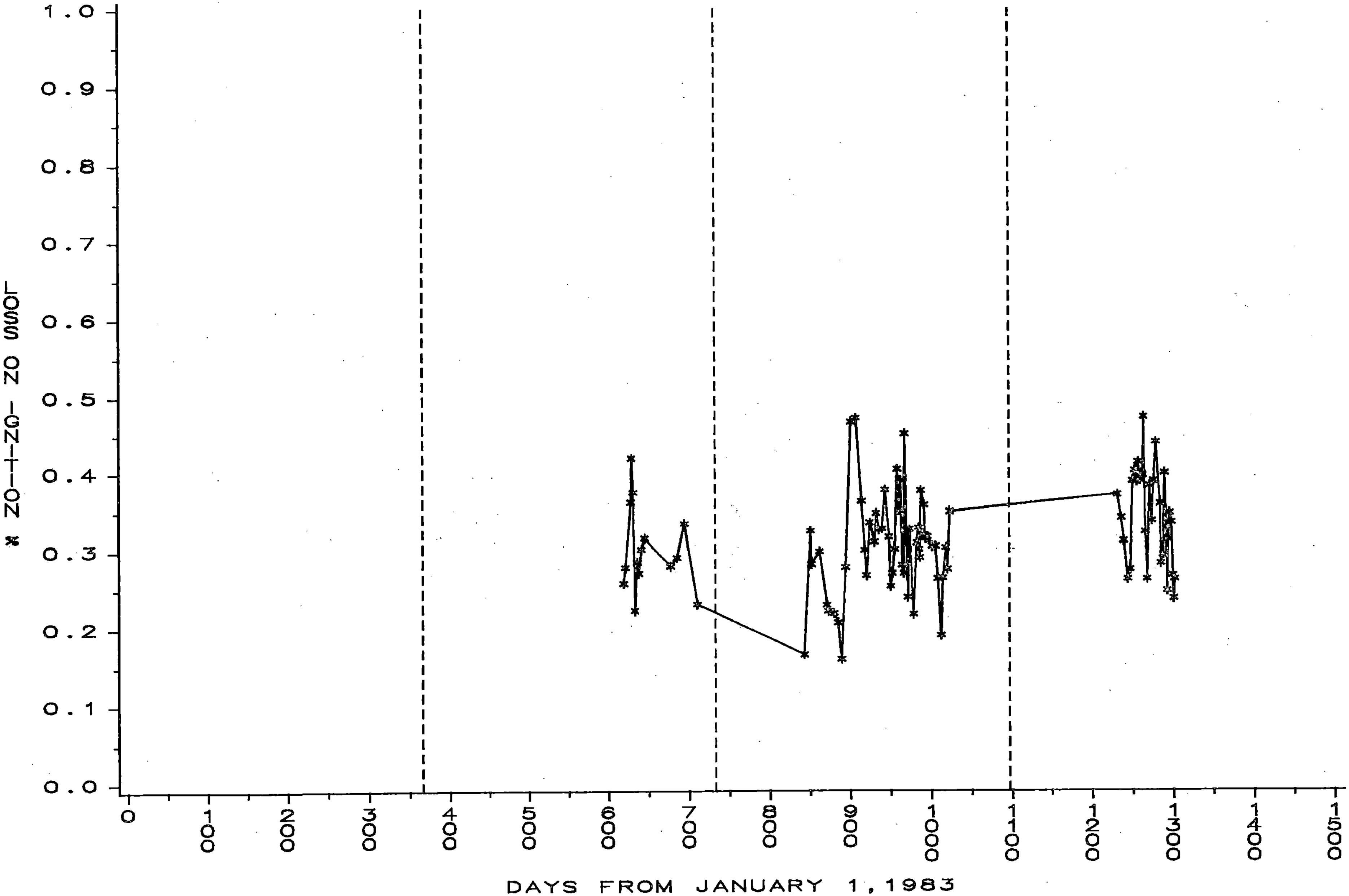

Figure 20, Appendix A

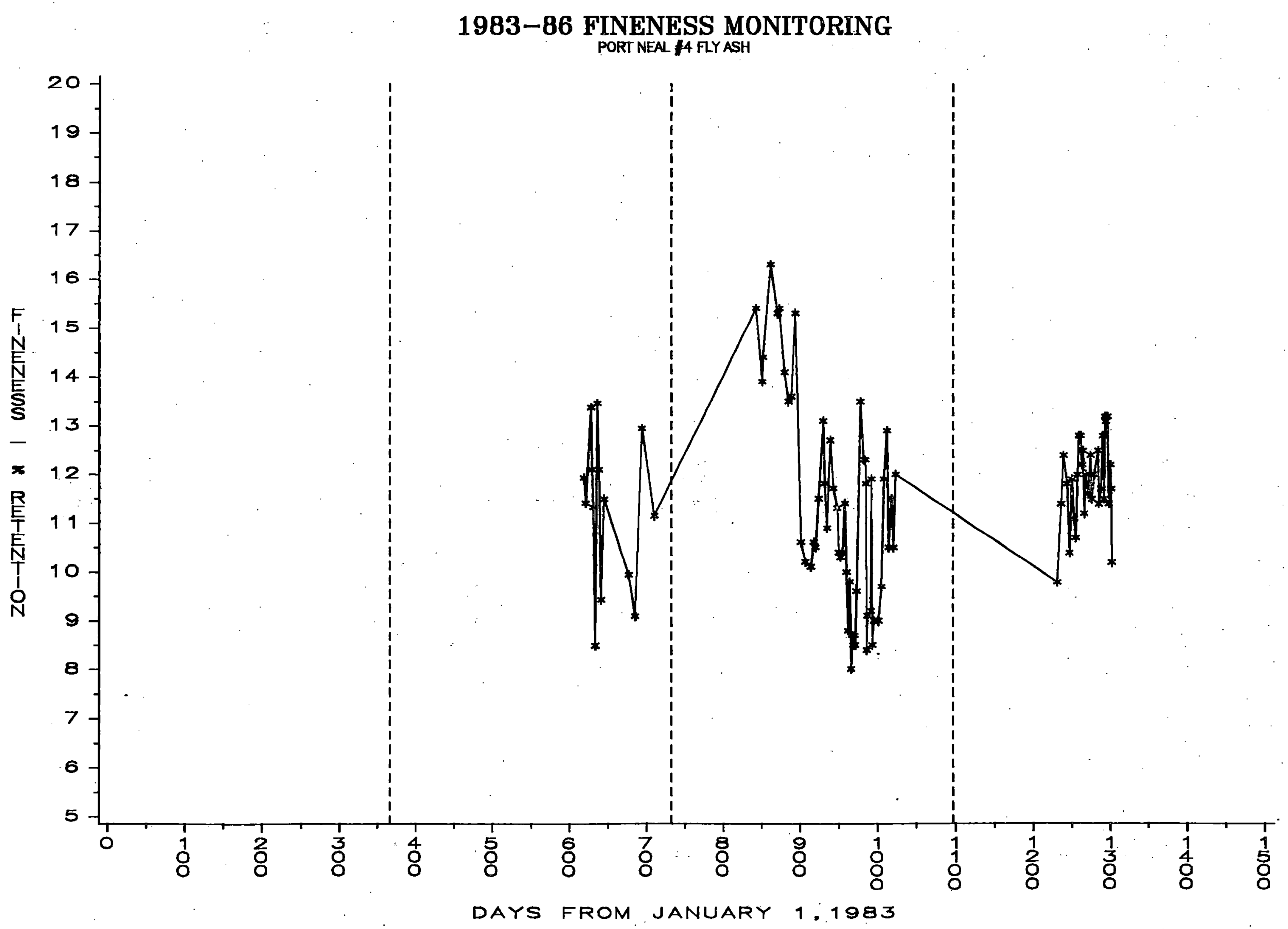

Figure 21, Appendix A

1983–86 7–DAY CEMENT POZZ MONITORING

PORT NEAL #4 FLY ASH

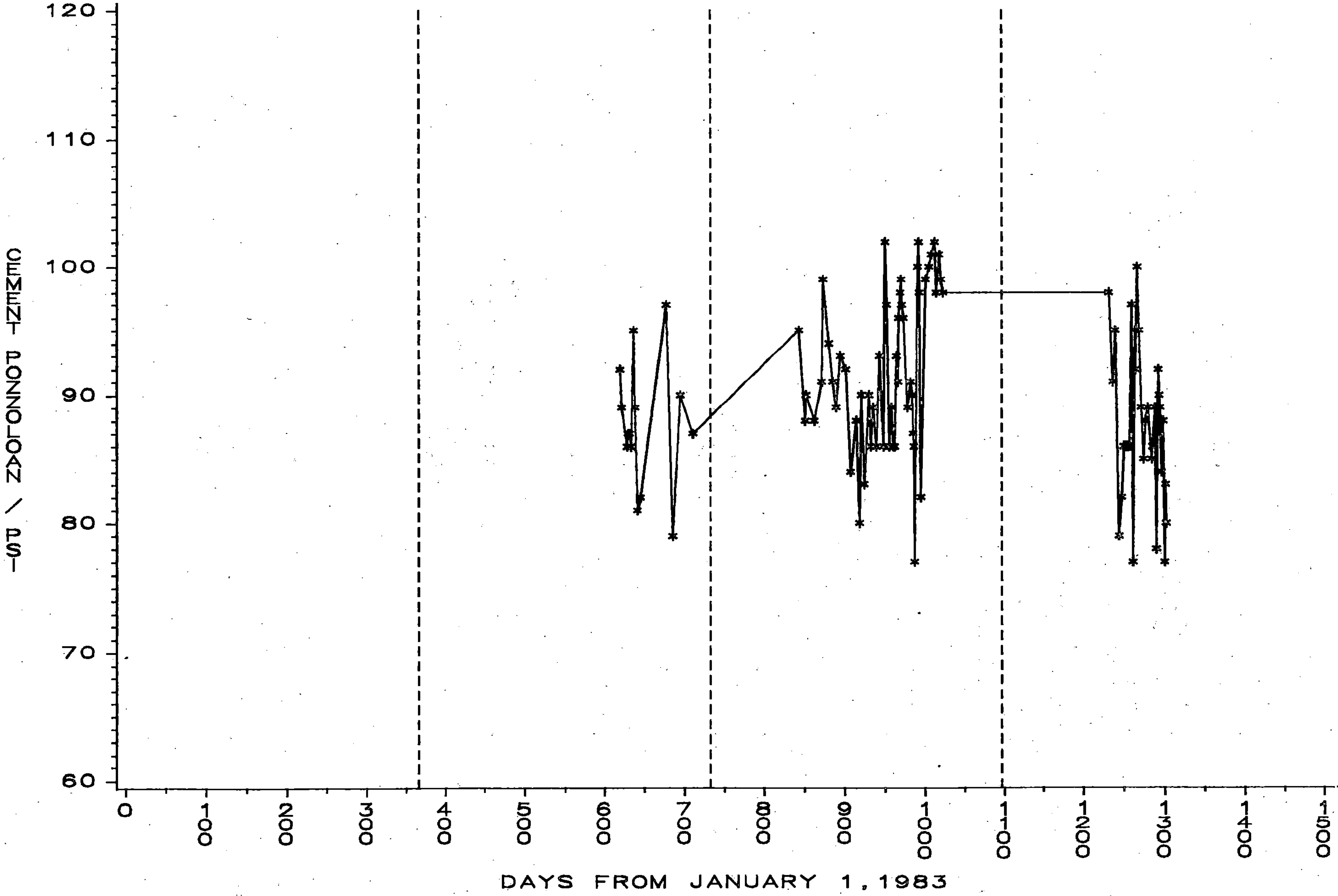

Figure 22, Appendix A

1983–86 AUTOCLAVE EXPANSION MONITORING

PORT NEAL #4 FLY ASH

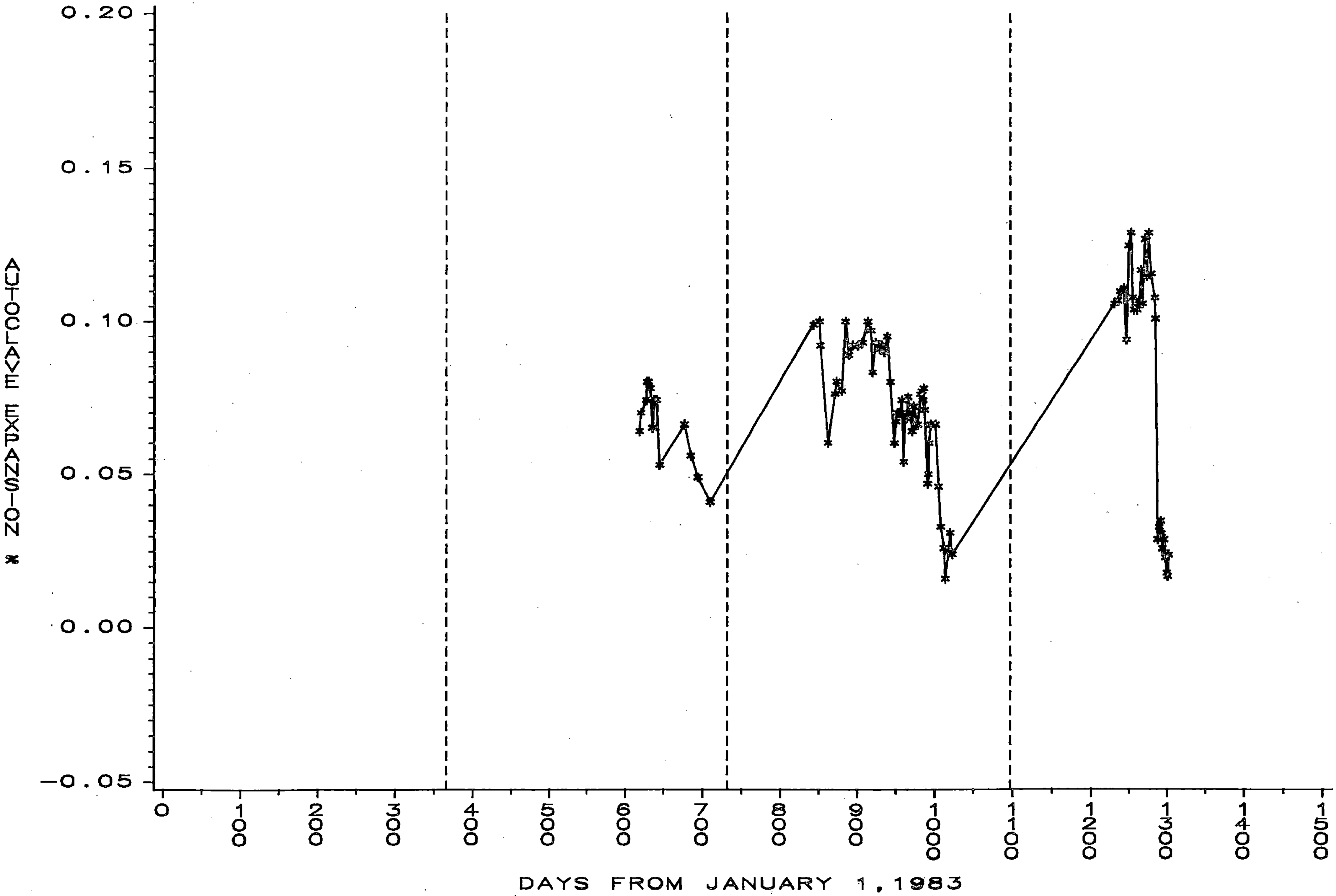

Figure 23, Appendix A

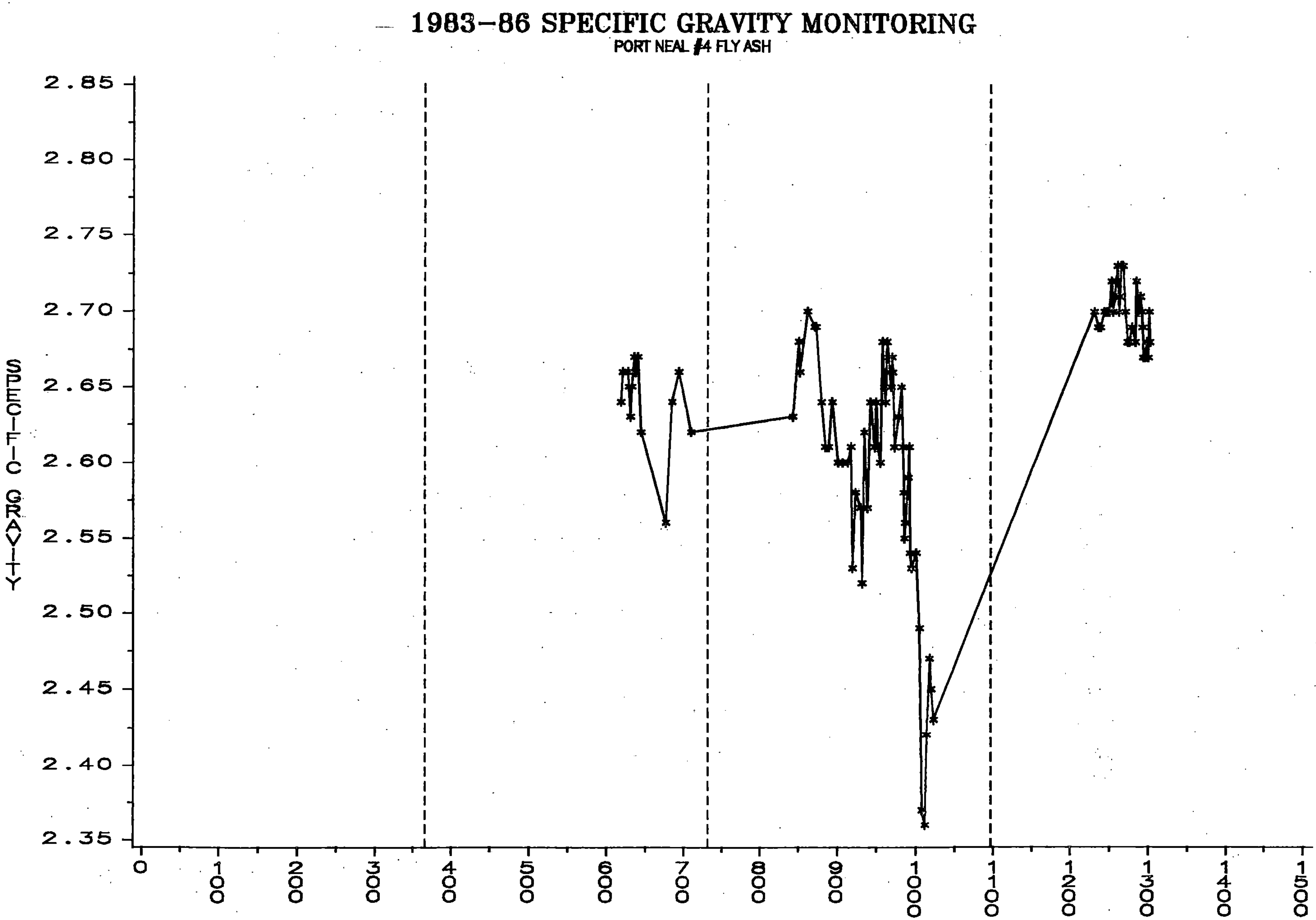

Figure 24, Appendix A

Table III, Appendix A

Type I portland cements used during 1986

oxide	A	B	C
CaO	63.8	63.1	63.4
SiO_2	21.9	21.2	21.5
Al_2O_3	4.71	4.86	4.05
Fe_2O_3	2.34	2.33	3.15
SO_3	2.58	2.72	2.33
MgO	1.93	2.20	2.87
K_2O	0.84	1.05	0.34
Na_2O	0.08	0.06	0.22
TiO_2	0.24	0.25	0.23

Average Compressive Strength

7-day	5110	5290	5100
28-day	5700	6040	6340

Table I, Appendix B

Repeatability test on Lansing Fly Ash, sampling date: 3/29/85.

	DAY 1		DAY 2		DAY 3		OVERALL	
	Mean	Std. Dev.	MEAN	Std. Dev.	MEAN	Std. Dev.	Mean	Std. Dev.
COMPRESSIVE STRENGTH (PSI)								
4-HOUR	---	---	2010	427	2096	195	2053	301
1-DAY	3171	132	3146	451	3321	230	3213	274
7-DAY	4915	850	4558	268	4356	427	4610	552
14-DAY	6039	807	5627	477	5172	370	5613	629
28-DAY	6134	---	4644	308	4680	---	5080	787
56-DAY	4499	1066	5822	816	5680	411	5334	943
VOLUME STABILITY (% exp. @ 28-days)								
Air Cured	-0.068	----	-0.062	---	-0.084	---	-0.071	0.011
Humid Cured	---	----	0.125	---	0.121	---	0.123	---
SET TIME (min.)								
Initial	9.5	---	10.0	---	10.5	---	10.0	0.5
Final	12.0	---	11.5	---	11.5	---	11.7	0.3
TEMPERATURE RISE								
ΔT (°C)	14.5	---	15.2	---	15.3	---	15.0	0.4
Peak Temp. (°C)	40.5	---	40.2	---	41.3	---	40.7	.6
Time to Peak(min)	23	---	22	---	20.5	---	21.8	1.3

Table II, Appendix B

Repeatability test on Ottumwa Fly Ash, sampling date: 2/25/85.

	DAY 1		DAY 2		DAY 3		OVERALL	
	Mean	Std. Dev.	MEAN	Std. Dev.	MEAN	Std. Dev.	Mean	Std. Dev.
COMPRESSIVE STRENGTH (PSI)								
4-HOUR	601	138	574	78	635	46	603	87
1-DAY	752	43	814	82	629	24	744	92
7-DAY	993	36	1014	179	886	159	964	139
14-DAY	1264	---	1131	175	1009	150	1118	163
28-DAY	1079	121	1054	100	760	127	964	184
56-DAY	1038	---	1101	343	1168	191	1110	223
VOLUME STABILITY (% exp. @ 28-days)								
Air Cured	-0.035	----	-0.037	---	-0.046	---	-0.039	0.006
Humid Cured	0.002	----	-0.001	---	0.016	---	0.006	0.009
SET TIME (min.)								
Initial	16	---	18	---	18	---	17.3	1.2
Final	25	---	27	---	29	---	27	2.0
TEMPERATURE RISE								
ΔT (°C)	4.3	---	6.9	---	4.7	---	5.3	1.4
Peak Temp. (°C)	30.3	---	29.9	---	29.7	---	30.0	0.3
Time to Peak(min)	56	---	53	---	61	---	56.7	4.0

Table III. Appendix B

Prior Results of Testing for Lansing (3/29/85) and Ottumwa (2/25/87) Fly Ash

LANSING FLY ASH (3/29/85), Testing Date: 7/1/85

COMPRESSIVE STRENGTH (PSI)

	Mean	Std. Dev.
4-HOUR	2143	134
1-DAY	3190	381
7-DAY	5370	370
14-DAY	5337	520
28-DAY	6203	335

VOLUME STABILITY (% exp. @ 28-days)

Air Cured	-0.009	---
Humid Cured	0.170	---

SET TIME (min.)

Initial	8	---
Final	10	---

TEMPERATURE RISE

ΔT (°C)	16.6	---
Peak Temp. (°C)	40.6	---
Time to Peak(min)	18.5	---

Table III (continued), Appendix B

OTTUMWA FLY ASH (2/25/85), Testing Date: 7/1/85

COMPRESSIVE STRENGTH (PSI)

	Mean	Std. Dev.
4-HOUR	448	104
1-DAY	550	166
7-DAY	700	52
14-DAY	890	128
28-DAY	950	72

VOLUME STABILITY (% exp. @ 28-days)

Air Cured	Broke	---
Humid Cured	0.0	---

SET TIME (min.)

Initial	12	---
Final	18.5	---

TEMPERATURE RISE

ΔT (°C)	7.3	---
Peak Temp. (°C)	29.8	---
Time to Peak(min)	57	---

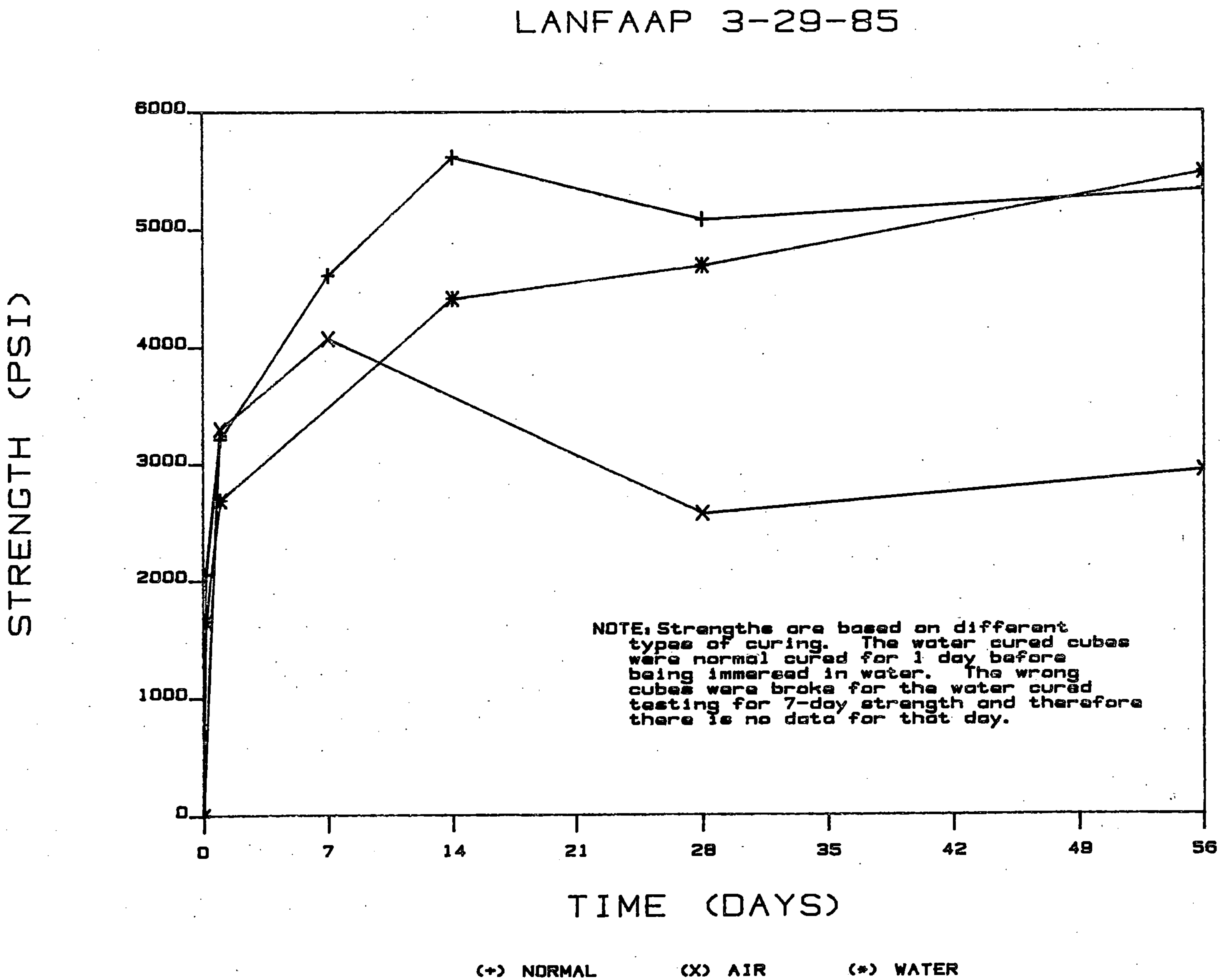

Figure 1, Appendix B

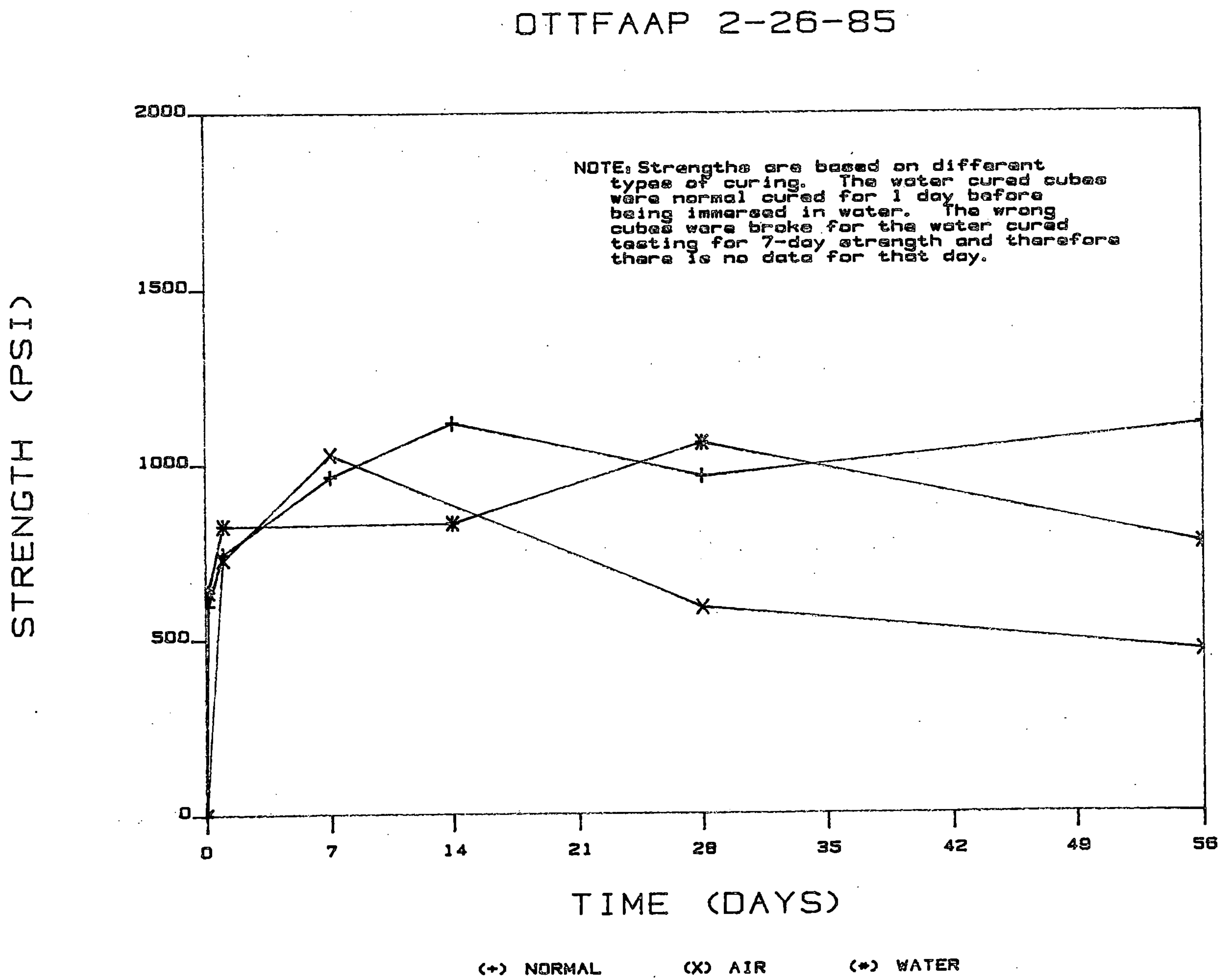

Figure 2, Appendix B

Table IV

Physical properties for Lansing fly ash pastes at different water/fly ash ratios.

LANSING FLY ASH (3/29/85)

	Water/fly ash Ratio			
STRENGTH (PSI)	0.27	0.35	0.45	0.55
4-HOUR	2053	1041	659	429
1-DAY	3213	1607	1053	652
7-DAY	4610	3012	2082	1135
14-DAY	5613	3577	2444	1478
28-DAY	5080	4491	2857	1863
VOLUME STABILITY (% expansion, 28-days curing)				
Air Cured	-0.07	-0.11	-0.12	-0.16
Humid Cured	0.12	0.19	0.15	0.12
SET TIME (min.)				
Initial	10.0	8.5	10.0	11.0
Final	12.0	9.5	11.0	13.0

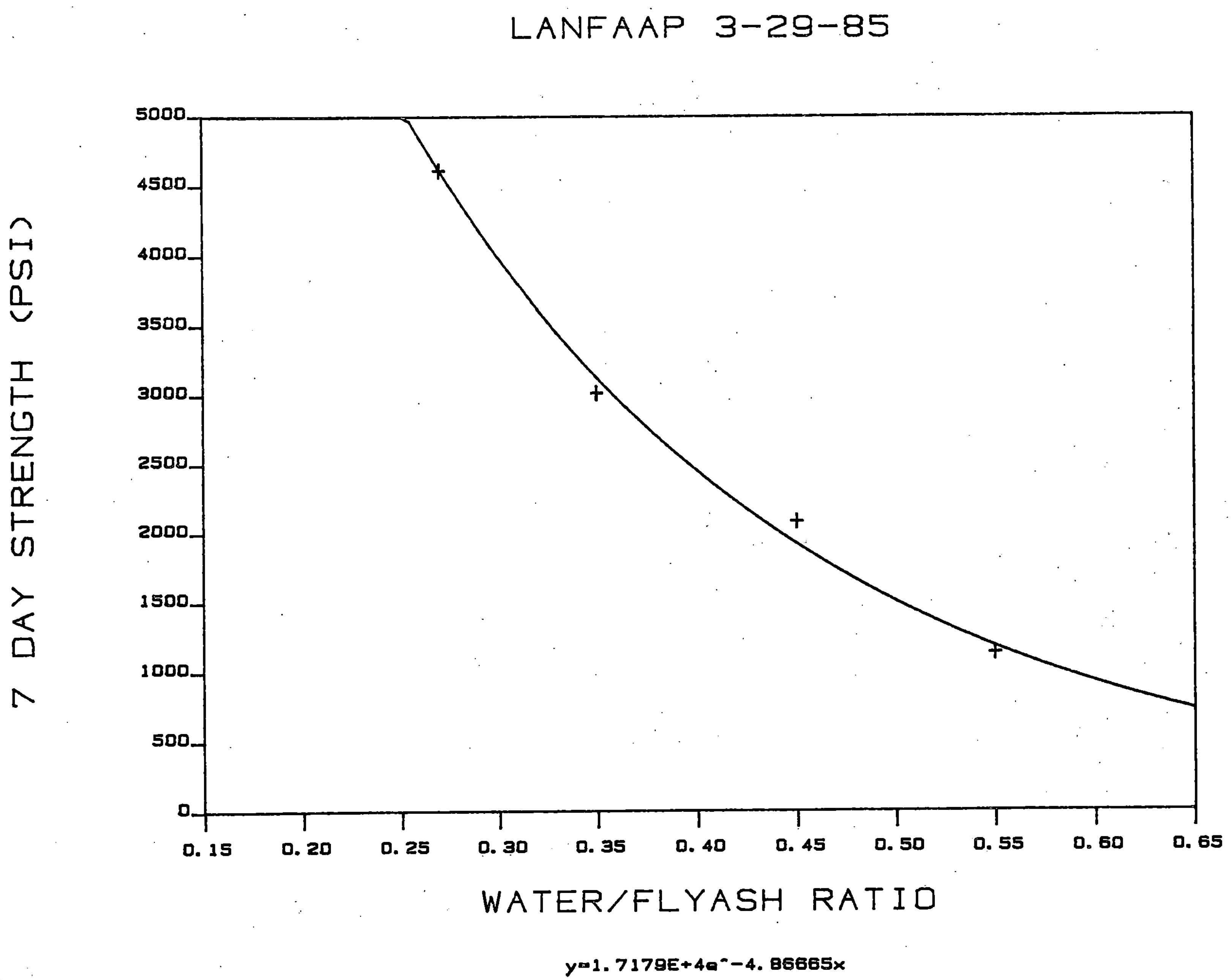

Figure 3, Appendix B

GENERAL INFORMATION (Fiscal year 1987)

A.) Power Plant Information

1.) **Name of power plant:** Ottumwa Generating Station

2.) **Location:** R.R. #4, Chillicothe, IA 52548 (physical location/truck address)
P.O. Box 219, Ottumwa, IA 52501 (mailing address)

3.) **Utility Company (owner):** Iowa Southern Utilities, Inc.

4.) **Year power plant came on line:** 1981

5.) **Net (maximum) generating capacity (MW):** 675 MWN

6.) **Actual output for 1986 (MW):** 3,252,723 MWH or 414 MWN average

7.) **Boiler type (or manufacturer):** Combustion Engineering - controlled circulation

8.) **Precipitator type:** Joy Western - hot side

a.) **Is an additive used to enhance the precipitators performance?** Yes, sodium carbonate

(If yes, what is the additive and its approximate dosage (lb/lb coal): 1 to 3 lbs/ton of coal

9.) **Tentative maintenance schedule for 1987:**

4/17/87 to 6/1/87
also
2 weeks scheduled October 1987

10.) **Name and phone number of a person who is employed at the power plant and who is technically capable of answering questions regarding the design and operation of the power plant.**

Name: Rick Grubb/Jay Dixson **Phone #:** 515-935-4301

Title: Superintendent/Supervisor of Operations

11.) **Start up fuel (assuming plant was totally shutdown):** Fuel oil #2

B.) Coal Information

1.) Coal Source (geographical location): Powder River Basin Wyoming

2.) Name of Mine(s): Cordero

3.) Name(s) of mining company(s): Sunedco

4.) Duration of coal contract (or date when current contract expires):
20 year contract ends around 2000

5.) Is anything other than coal burnt at the power plant? (If yes, then how much is burnt per pound of coal).

No

C. Fly Ash Information

1.) Annual ash production (Tons/year): 78,600 tons (1986)

2.) Storage capacity of silo (tons): 3,500 tons

3.) Method of loading trucks (i.e. pneumatic, auger, etc.): Gravity feed

4.) Number of loading stations at silo: 2

5.) Approximate amount of fly ash sold per year (Tons): 33,900 tons (1986)

6.) Most common method used to dispose of the unused fly ash (landfill, sluice pond, etc.): Stripmine reclamation

a.) Where is the location of the disposal site?: 5 miles north of the plant

7.) How are fly ash samples obtained from the power plant (i.e., grab samples from trucks, composite sampling, etc.)?: Grab samples