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16. Abstract

Five individual cathodic protection systems were installed on the U.S. 87 Missouri-Pacific Railroad overpass structure in Big Spring, Texas. The cathodic protection systems were installed in October 1988 as a demonstration project to compare the various systems. Three distributed anode types were used to protect the bridge deck: (1) titanium mesh; (2) conductive polymer; and (3) carbon strand. A hot-sprayed zinc conductive coating anode was applied to sidewalks and a median on the bridge deck, and a conductive paint anode was applied to a bridgebent. Performance data have been collected for each system since installation.

The titanium mesh anode continues to function while the conductive polymer anode has failed and the carbon strand anode exhibits instability. The hot-sprayed zinc anode system failed early in the study and the conductive paint anode system shows signs of failure.

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Initial Analysis of Cathodic Protection Systems On US 87 Railroad Overpass Bridge Big Spring, Texas

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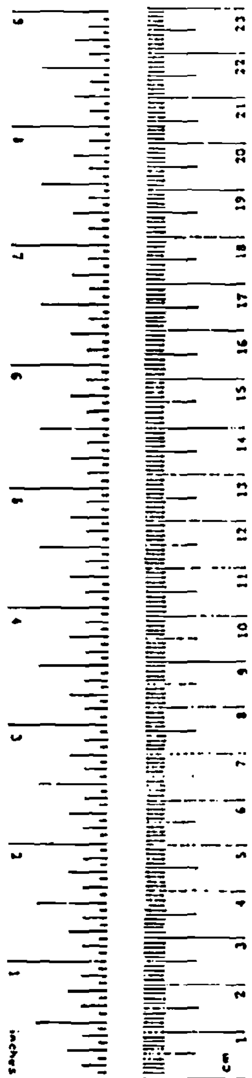
There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

METRIC CONVERSION FACTORS

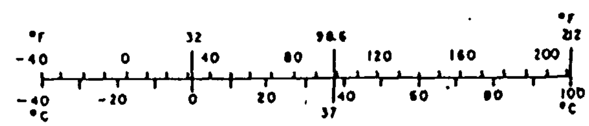
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



METRIC CONVERSION FACTORS

EXECUTIVE SUMMARY

As a pioneering study of the use of cathodic protection to mitigate corrosion of reinforced concrete, five cathodic protection systems were installed on the US 87 railroad overpass bridge in Big Spring, Texas by the Texas Department of Transportation (TxDOT). The systems have been in operation since mid 1988 and performance data has been collected since their installation. In a research study with TxDOT, Texas Tech University is evaluating the effectiveness of each system and developing guidelines for future studies and implementations of cathodic bridge protection systems. The purpose of this report is to summarize initial inspections of the cathodic protection systems and evaluations of the data collected since installation.

Results from the initial data analysis provide the following indications:

(1) Elgard 150 mesh has exhibited long term stable operation with only brief periods of irregular behavior

(2) After approximately 1,000 days of operation, the Raychem Ferex 100 system deteriorated, and no longer appears to be functioning

(3) Rescon rigid conductive polymer appears to be functioning after more than 1300 days of operation, but recent irregularities in the data could be an indication of system deterioration

(4) Sprayed zinc circuits completely failed early in the study (at approximately 200 days after installation)

(5) Porter DAC-85 has remained reasonably stable with on minor irregularities.

IMPLEMENTATION STATEMENT

Findings and results from this study will be used to choose the most appropriate bridge protection system for future projects. Recommendations from the evaluation will serve as a basis for including cathodic protection system options in future bridge design guidelines. These guideline supplements will be provided as they become available.

This final report was prepared to serve as a guideline for training TxDOT personnel in the principles and applications of cathodic protection. This document will reduce dependence upon outside contractors for system evaluations and help reduce any bias in evaluating future systems.

TABLE OF CONTENTS

INTRODUCTION

This report contains the initial analysis of performance data for five different cathodic protection systems installed on the US 87 Railroad Overpass Bridge in Big Spring, Texas. Performance data for the cathodic protection systems was collected for a period of more than three years. Research reported herein is in support of the Texas Department of Transportation (TxDOT) Study 9-500 (total funding of $78,630) which began March 12, 1992. Research objectives are as follows:

(1) Determine the effectiveness of each cathodic protection system in preventing corrosion of the reinforcing steel

(2) Identify the most cost-effective system

(3) Provide training for TxDOT personnel to facilitate future in-house evaluations

(4) Recommend a schedule of future evaluations and data collection

(5) Report findings of the study

Evaluations in pursuit of the first objective include determining which systems are still operational and analyzing data obtained since initial installation of each system. This interim report summarizes findings from initial investigations and recommends procedures for operating cathodic protection systems and improving data collection.

The initial source of information for the project has been the report by Smith[1] describing the bridge rehabilitation and installation of the cathodic protection systems. Smith's report provides bridge description details important to understanding the data reported herein, and readers are urged to refer to Smith's report for specific details on the bridge description. Smith's report also contains a report written by consultants (Bushman[2]) regarding initial energization of the cathodic protection systems and inspections and readjustments after approximately 45 and 90 days of operation. Information since Bushman's reporting consists of

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[1]Smith, Linda, "Cathodic Bridge Deck Protection," Rept. No. TX/91-500/554-1, Texas Department of Transportation, Austin, Texas, August, 1990.

[2] Bushman, J.B., W.J. Swiat, and T.G. Rizk, "Howard County U.S. 87 Railroad Overpass Bridge, Big Spring, Texas - Final report of the Cathodic Protection Systems, Corrpro Companies, Inc. Medina, Ohio, April, 1989.

monthly data sheets completed by Big Spring TxDOT employees which log the pertinent parameters for the operation of the cathodic protection systems. In addition the bridge has been visited by Texas Tech personnel and meetings have been held with TxDOT personnel regarding the project.

ORGANIZATION OF THE DATA

The data from both the consultants report and the monthly data sheets have been entered into a spreadsheet format for convenience in data reduction and reporting. A listing of the data spreadsheet is attached as Appendix A. Data collected for any specific date is presented in a single column. Data collected for any specific circuit within the cathodic protection systems is presented in a single row. Seventeen (17) circuits were used for the five cathodic protection systems as listed below.

Anode Material	Manufacturer Designation	Zones	Location	Circuits
Titanium Wire Mesh	Elgard 150 Mixed Metal Oxide Mesh	A1-A4	Deck Slab	1-4
Conductive Cable	Raychem Ferex 100 Flexible Conductive Polymer	B1-B4	Deck Slab	5-8
Carbon Strand	Rescon Rigid Conductive Polymer	C1-C2	Deck Slab	9-10
Hot-Sprayed Zinc	Metallized Spray Zinc	D1-D6	Sidewalks	11-16
Conductive Paint	Porter DAC-85 Conductive Paint	E	Pier Cap	17

Time histories are given in Appendix B for each of the data items which will be discussed in the next section of this report. The time-history plots are ordered first with regard to circuit number, and then the individual data items.

GENERAL DISCUSSION OF THE DATA

The significance of each of the data items will be discussed before considering the performance of each type of cathodic protection systems individually. Data items to be discussed are as follows:

- Anode Current
- Anode Voltage
- Anode Conductance
- Reference Cell Voltage
- Instant-off Reference Cell Voltage
- Rebar Probe Voltage
- Corrosion Rates via 3LP Procedure

There are two reasons for gathering and analyzing the data items listed above: (1) to determine if the systems are performing as designed and adjusted for cathodic protection of the reinforced concrete bridge, and; (2) to estimate if the specified level of cathodic protection is adequate to prevent corrosion.

Anode Current Anode current is the primary variable which is directly adjusted by the engineer to provide adequate cathodic protection of the bridge. Inadequate current may result in ineffective cathodic protection of the bridge, and excessive current may directly damage the bonding of concrete to the rebar and/or cause hydrogen embrittlement of the rebar. Criteria by which the adequacy of cathodic protection are determined have been discussed in the literature[3] and a recommended practice established in documents which have been ordered, but not yet received.

The consultant during the installation of the cathodic protection systems established the desired currents for each of the 17 circuits based on E vs log(I) data taken on each circuit. Sufficient current was supplied to cause the protected rebar potential, with respect to the reference cell, to be in the linear, all-cathodic region, observed on the E vs log(I) plot. Exceptions were made to this adjustment

[3] Stratfull, R.F., "Criteria for the Cathodic Protection of Bridge Decks," Chapter 18 in Corrosion of Reinforcement in Concrete Construction, Society of Chemical Engineers, Chichester, West Sussex, England, 1983.

criteria when the current required would be in excess of the manufacturers recommendation for the particular anode system. After approximately 45 and 90 days of operation, the anode current settings for each cathodic protection system were adjusted on the basis of a positive depolarization shift of 100 to 150 mv. The depolarization shift is the potential between the reference cell and the rebar measured at instant-off conditions and after 4 hours without power, and initial measurements are reported in Table 16 of the consultants report. Based upon depolarization shifts, currents to the anode systems were adjusted as listed in Table 23 of the consultants report. The current adjustments have not been changed since the adjustment after 90 days of operation.

Anode Voltage The anode voltage is automatically adjusted by each rectifier circuit to supply the current selected for each cathodic protection circuit. The maximum available anode voltage is determined by the rectifier design. For the rectifier system installed at the Big Spring bridge, the maximum available voltage is 25 volts for circuits 1-13 and 50 volts for circuits 14-17. If the resistance in a cathodic protection circuit increases, the voltage is automatically increased by the rectifier to provided the selected current until the maximum voltage available from the circuit is achieved.

Anode Conductance Anode conductance is calculated by dividing the anode current by the anode voltage. Its units are reciprocal ohms, frequently called mohs. This parameter has been found useful in observing the failure of the cathodic protection circuits on the Big Spring bridge -- as the conductance of a circuit approaches zero the resistance of the circuit approaches infinity, and it is impossible to supply the required amount of current to it.

Reference Cell Voltage Reference cell voltage is the potential measured between the reference cell and the adjacent rebar. The voltage may vary from location to location. For the bridge deck, silver chloride reference cells are placed in the center of each protected zone. The locations of the reference cells in the other systems have not yet been established. If the reference cell measurements are stable, observed changes in reference cell potential reflect changes in the potential of the rebar. Reference cell voltages are recorded and plotted as positive voltages. By the conventions of electrochemistry, these voltages would be considered negative, and larger values would indicate that the rebar was more negative, that is more cathodic, therefore 'better protected'. Unfortunately, reference cell potentials may not be stable over long periods or extremes of temperature. Reference cell stability has been discussed in the literature.[4] The

[4] Schell, H.C., D.G. Manning, and F. Pianca, "Embedded Reference Cells for Use in Cathodically Protected Concrete," Transportation Research Record 1211, 1989.

problem of reference cell stability is minimized when polarization shifts are used to evaluate the adequacy of the current supplied to a cathodic protection circuit, as the consultant did in his 45- and 90-day adjustments of the currents to the present cathodic protection systems. Even with a stable reference cell the observed reference cell voltages fluctuate considerably. Voltage fluctuations have been attributed to the varying availability of oxygen to the cathode, due to changes in moisture within the concrete.[5] The voltage gradients induced in the concrete by the anode current are also measured as a part of the observed reference potentials. Voltage gradient problems are circumvented by using 'instant-off' reference cell voltages as discussed in the next paragraph.

Instant-off Reference Cell Voltages The voltage gradients in the slab caused by the current flowing through the slab can be eliminated by turning the current off, and instantly measuring the reference cell voltage. In this case the term 'instant' must be defined since the anode begins to depolarize 'instantly'. The instructions provided to personnel taking data at the Big Spring bridge was to record the second reading on the digital voltmeter after cut-off of the anode current.

Rebar Probe Voltage The rebar probe voltage is actually measured across a ten-ohm shunt connecting the rebar probe to the remainder of the rebar being cathodically protected, so it really is a measurement of rebar probe current, and the voltage value can be multiplied by 100 to get the rebar current in milliamps. If the current flowing from the rebar probe is positive the probe is negative with respect to the remaining rebar, and so is more cathodic and better protected than the remaining rebar. If the current flow is negative the rebar probe is actually corroding. The rebar probe current is not an absolute measurement of corrosion rates, since the probe could contain both anodic and cathodic sections, and we are observing only the net external current flow. To obtain an actual measurement of corrosion rates more complex procedures are required.

Corrosion Rates via 3LP Measurements Corrosion rates can be directly measured by the linear polarization method. This technique is based on proven theory, and has been adapted for use in reinforced concrete structures. However, 3LP measurements can not be used while the bridge is being cathodically protected.[6] Twenty 3LP probes have been installed on the bridge, and a portable probe is available for additional measurements. The consultant took three sets of measurements prior to energizing the cathodic protection system, and after

[5] Stratfull, R.F. Ibid. p. 319.

[6] Clear, K.C., "Measuring Rate of Corrosion of Steel in Field Concrete Structures," Transportation Research Record 1211, p.28, 1989.

approximately 45 and 90 days of operation. Results from the initial 3LP measurements are given in Table 19 of the consultants report. The data indicated corrosion rates of about 2 mils per year at six locations which would normally predict slab failure in 2 to 10 years[7]. Measurements with the 3LP system require the cathodic protection system current be turned off for 24 to 48 hours prior to testing, so measurements exhibit little or no relation to corrosion rates observed while the bridge is under cathodic protection. One additional set of 3LP measurements was gathered after 546 days of operation.

INITIAL DATA ANALYSIS

Data from each cathodic protection circuit will be considered in groups which contain the same anode materials. Reference should be made to the plots in Appendix B when reading this section of the report.

Elgard 150 mesh (Bridge deck Zones A1-A4 , Rectifier Circuits 1-4) Circuits protected by Elgard 150 mesh exhibited stable, long term operation, as evidenced by maintaining the desired anode current (Figure B-1) without significant increases in anode voltage (Figure B-2). The rebar probe voltage remained positive, indicating the probe was cathodic with respect to the remainder of the rebar.

There is some evidence of irregular behavior of the reference electrode in zone A1 (circuit 1), beginning approximately 550 days after system start-up, as indicated by the decrease in instant-off potential from 300 to about 10 mv (Figure B-4).

Raychem Ferex 100 (Bridge Deck Zones B1-B4, Rectifier Circuits 5-8) Circuits protected by Raychem Ferex 100 performed satisfactorily for approximately 550 days at which time voltage increases (Figure B-7) were necessary to maintain the desired anode current. After 1000 days of operation the rectifier was unable to supply sufficient voltage (Figure B-7) to maintain the current, so the anode current began to decrease (Figure B-6). After approximately 1100 days of operation, none of the circuits were receiving a significant amount of electrical current (Figure B-6). Deterioration of the circuits is better seen in a plot of circuit conductance versus time (Figure B-11). The mean decrease in conductance is linear with time from 300 days to 1100 days. Linear decreases in conductance shown in Figure B-11 suggest that deterioration of the circuits began approximately 300 days after system start-up, but the deterioration was obscured by irregularities in the data.

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[7] Clear, K.C., Ibid. p.36

After current ceased to be supplied to circuits 5 through 8, the instant-off reference cell voltages decreased by more than 300 mv for each circuit (Figure B-9). The decrease was greater than the 300 mv observed before energizing the cathodic protection systems. The rebar probe voltage decreased by a factor of approximately 3 (Figure B-8), also as an apparent result of insufficient current to the anode systems. Voltage drop observations are consistent with expectations for the loss of cathodic protection.

Rescon Rigid Conductive Polymer (Bridge Deck Zones C1 & C2, Circuits 9 and 10) The desired anode current has been maintained in circuits 9 and 10 thus far, 1300 days (Figure B-12). However, after 1100 days of operation, the voltage required to maintain the desired current began increasing rapidly (Figure B-13). At the same time, the instant-off reference cell voltages in circuit 10 decreased from 350 mv to 80 mv (Figure B-15). The relatively rapid increase in anode voltage over the period of 200 days (Figure B-13) could be a indication of future difficulties regarding the two circuits using the Rescon anodes. Less than 9 volts were required for the circuits at the time of the last measurement, and the rectifier can supply up to 25 volts to the circuits.

Sprayed Zinc (Sidewalks and Median Zones D1-D6, Circuits 11-16) Based upon anode currents and voltages (Figures B-17, B-21, B-18 and B-22), it appears that all of the zinc sprayed circuits have failed. In fact this failure occurred rather quickly, at about 200 to 300 days after system start-up. The easiest way to observe these failures is to note the step rise in anode voltage to the maximum possible supplied by the rectifier (Figures B-18 and B-22). A similar conclusion can be drawn by looking at the plots of conductance. Table 20 in the consultant's report noted high resistances and increasing resistances in three of the circuits, 11, 12, and 13, in the first 90 days of operation. It appears that a combination of disbondment and cracking of the zinc caused these failures. The rebar currents have been quite low (Figures B-17 and B-21) after failure to supply current to the anodes, and some times they were negative indicating that the rebar probe was anodic with respect to the remaining rebar. In contrast, the instant-off cell voltages have remained relatively constant (Figures B-20 and B-24).

Porter DAC-85 (Pier cap Zone E, Circuit 17) On the average, the current to circuit 17 has remained satisfactory, but there are unexplained one-time changes in anode current and corresponding changes in anode voltage (Figures B-26 and B-27). There may be an intermittent short or open in a portion of this anode system. The instant-off reference cell voltage has remained relatively steady (Figure B-29), and the rebar probe voltage (Figure B-28) has decreased consistently.

CONCLUSIONS AND RECOMMENDATIONS

Bridge Status and Operational Concerns This preliminary analysis of approximately 1300 days of cathodic protection has indicated several areas of concern, both for this particular bridge and with regard to cathodic protection in general. The following actions and non-actions are proposed.

- Adjustments of current supplied to the operational anode systems be delayed until depolarization measurements, an accepted means of determining the adequacy of the current, have been made.

- Remedial actions for the anode circuits which have failed be delayed until 3LP corrosion rate measurements have been made on the portions of the bridge which are now unprotected.

- The reasons for failure of the Raychem and sprayed zinc anodes should be better defined, both by examination bridge and consultations with vendors. The potential instabilities in the Porter conductive paint anode system and the increased anode voltage requirements for the Rescon conductive polymer systems should also be investigated.

Data acquisition procedures In addition to taking data on a monthly basis as done previously, the following data acquisition activities are recommended.

- 3LP corrosion rate measurements should be made for the entire bridge, at first on a monthly basis to establish a base line. This will be particularly useful for the portions of the structure where the anode systems have failed. If severe corrosion is occurring in these unprotected zones, consideration will have to be given to remedial measures.

- Four-hour depolarization measurements should be made on each operable anode circuit, so that this accepted criteria for adequacy of cathodic protection will be available, both to adjust currents supplied to the anodes and as a matter of record for the research.

- AC resistance measurements be made for anodes and reference cells for comparison to similar measurements made by the consultant. These measurements would also be helpful diagnosing the reasons for failure of several anode circuits.

APPENDIX A

DATA LISTING

EVALUATION OF CATHODIC BRIDGE PROTECTION SYSTEMS

APPENDIX A

Data spreadsheet

Client: Texas Department of Transportation
Mr. Bill Burnett, Project Coordinator

Performed at: The College of Engineering,
Texas Tech University,
Lubbock, Texas

Faculty: Harry W. Parker, Ph.D, P.E.
Phil Nash, P.E.

Research Assistant: Robert W. Feingold

Date:	10/28/88	10/28/88	12/13/88	12/15/88	1/31/89	2/1/89	2/2/89	3/13/89	4/13/89
Days since last reading:	23	23	46	2	47	1	1	152	31
Days since start-up (10/5/88):	23	23	69	71	118	119	120	272	303
Tester:	Corrpro	Corrpro	Corrpro	Corrpro	Corrpro	Corrpro	Corrpro	MC,DR,DE	DR,DE,TD
# 1: TITANIUM MESH									
Rebar Probe (volts)	-0.01380	-0.00200	0.006	0.010	0.005	0.002	0.004	0.006	0.006
Reference Cell (volts)	0.360	0.449	0.541	0.501	0.508	0.404	0.479	0.461	0.532
Anode Voltage	0.57	4.98	5.6	5.2	5.4	5.4	5.5	5.6	5.8
Anode Current (amps)	0.00	4.50	4.62	4.50	4.44	4.80	4.85	4.93	4.95
Ref. Cell Instant-off (volts)		0.401	0.511	0.450	0.440	0.371	0.418		
Conductance (mohs)		0.904	0.825	0.865	0.822	0.889	0.882	0.880	0.853
Voltage drop in ref. circuit		0.048	0.030	0.051	0.068	0.033	0.061		
# 2: TITANIUM MESH									
Rebar Probe (volts)	-0.00670	0.00200	0.006	0.007	0.004	0.005	0.004	0.005	0.005
Reference Cell (volts)	0.304	0.588	0.711	0.640	0.616	0.508	0.574	0.543	0.632
Anode Voltage	0.45	4.71	5.3	4.6	4.8	4.6	4.7	4.8	5.0
Anode Current (amps)	0.00	4.00	4.11	3.48	3.44	3.55	3.56	3.64	3.65
Ref. Cell Instant-off (volts)		0.416	0.566	0.489	0.465	0.395	0.449		
Conductance (mohs)		0.849	0.775	0.757	0.717	0.772	0.757	0.758	0.730
Voltage drop in ref. circuit		0.172	0.145	0.151	0.151	0.113	0.125		
# 3: TITANIUM MESH									
Rebar Probe (volts)	-0.00290	0.00200	0.006	0.004	0.002	0.005	0.005	0.005	0.004
Reference Cell (volts)	0.266	0.427	0.668	0.596	0.557	0.441	0.501	0.466	0.525
Anode Voltage	0.46	4.68	5.9	5.1	5.4	4.8	5.1	5.2	5.6
Anode Current (amps)	0.00	3.50	3.62	3.19	3.15	3.26	3.28	3.35	3.36
Ref. Cell Instant-off (volts)		0.360	0.532	0.461	0.425	0.380	0.392		
Conductance (mohs)		0.748	0.614	0.625	0.583	0.679	0.643	0.644	0.600
Voltage drop in ref. circuit		0.067	0.136	0.135	0.132	0.061	0.109		
# 4: TITANIUM MESH									
Rebar Probe (volts)	-0.00200	0.00200	0.005	0.005	0.004	0.005	0.004	0.006	0.005
Reference Cell (volts)	0.352	0.460	0.546	0.510	0.505	0.428	0.485	0.466	0.508
Anode Voltage	0.45	4.83	5.7	5.2	5.5	5.3	5.5	5.7	6.0
Anode Current (amps)	0.00	4.50	4.62	4.50	4.44	4.81	4.86	4.97	4.99
Ref. Cell Instant-off (volts)		0.410	0.514	0.456	0.443	0.389	0.433		
Conductance (mohs)		0.932	0.811	0.865	0.807	0.908	0.884	0.872	0.832
Voltage drop in ref. circuit		0.050	0.032	0.054	0.062	0.039	0.052		
1-4: AVERAGE VALUES: TITANIUM MESH									
Rebar Probe (volts)	-0.006	0.001	0.006	0.007	0.004	0.004	0.004	0.006	0.005
Reference Cell (volts)	0.321	0.481	0.617	0.562	0.547	0.445	0.510	0.484	0.549
Anode Voltage	0.5	4.8	5.6	5.0	5.3	5.0	5.2	5.3	5.6
Anode Current (amps)	0.00	4.13	4.24	3.92	3.87	4.10	4.14	4.22	4.24
Ref. Cell Instant-off (volts)		0.397	0.531	0.464	0.443	0.384	0.423	0.000	0.000
Conductance (mohs)		0.858	0.756	0.778	0.732	0.812	0.792	0.789	0.754
Voltage drop in ref. circuit		0.084	0.086	0.098	0.103	0.061	0.087	0.000	0.000

EVALUATION OF CATHODIC
BRIDGE PROTECTION SYSTEMS

APPENDIX A

Data spreadsheet

Key to tester names:
MC - Mike Chetty
DR - Dan Richardson
DE - David Elmore
TD - Todd Darden
JM - John Moore
KC - Ken Corse

Date:	5/26/89	6/13/89	7/17/89	8/18/89	9/19/89	10/31/89	11/28/89	1/9/90	1/17/90
Days since last reading:	43	18	34	32	32	42	28	12	8
Days since start-up (10/5/88):	346	364	398	430	462	504	532	544	552
Tester:	DR	JM,DR	DR,KC	DR	DR	DR	DR	DR,DE	DR
# 1: TITANIUM MESH									
Rebar Probe (volts)	0.006	0.006	0.009	0.009	0.006	0.005	0.005	0.005	0.006
Reference Cell (volts)	0.371	0.442	0.416	0.403	0.505	0.525	0.744	0.542	0.551
Anode Voltage	5.3	5.6	5.6	5.6	5.9	5.9	6.3	5.9	5.8
Anode Current (amps)	4.85	4.87	4.78	4.80	4.83	4.85	4.99	4.90	4.87
Ref. Cell Instant-off (volts)								0.354	
Conductance (mohs)	0.915	0.870	0.854	0.857	0.819	0.822	0.792	0.831	0.840
Voltage drop in ref. circuit								0.188	
# 2: TITANIUM MESH									
Rebar Probe (volts)	0.006	0.006	0.008	0.009	0.005	0.006	0.004	0.005	0.006
Reference Cell (volts)	0.438	0.523	0.486	0.498	0.605	0.718	0.984	0.722	0.725
Anode Voltage	4.5	4.8	4.8	4.8	5.1	5.2	5.7	5.2	5.1
Anode Current (amps)	3.57	3.59	3.49	3.50	3.54	3.56	3.68	3.62	3.59
Ref. Cell Instant-off (volts)								0.382	
Conductance (mohs)	0.793	0.748	0.727	0.729	0.694	0.685	0.646	0.696	0.704
Voltage drop in ref. circuit								0.340	
# 3: TITANIUM MESH									
Rebar Probe (volts)	0.006	0.005	0.009	0.008	0.005	0.005	0.004	0.004	0.005
Reference Cell (volts)	0.364	0.411	0.388	0.375	0.423	0.456	0.599	0.489	0.483
Anode Voltage	4.6	5.3	5.1	4.9	5.8	5.8	7.1	5.7	5.6
Anode Current (amps)	3.29	3.33	3.29	3.25	3.27	3.30	3.41	3.35	3.32
Ref. Cell Instant-off (volts)								0.351	
Conductance (mohs)	0.715	0.628	0.645	0.663	0.564	0.569	0.480	0.588	0.593
Voltage drop in ref. circuit								0.138	
# 4: TITANIUM MESH									
Rebar Probe (volts)	0.007	0.005	0.008	0.008	0.005	0.004	0.004	0.004	0.005
Reference Cell (volts)	0.395	0.426	0.406	0.393	0.428	0.445	0.546	0.491	0.480
Anode Voltage	5.3	5.7	5.6	5.5	6.0	6.0	6.8	6.0	5.9
Anode Current (amps)	4.90	4.92	4.81	4.81	4.85	4.89	5.04	4.97	4.93
Ref. Cell Instant-off (volts)								0.383	
Conductance (mohs)	0.925	0.863	0.859	0.875	0.808	0.815	0.741	0.828	0.836
Voltage drop in ref. circuit								0.108	
1-4: AVERAGE VALUES: TITANIUM MESH									
Rebar Probe (volts)	0.006	0.006	0.009	0.009	0.005	0.005	0.004	0.005	0.006
Reference Cell (volts)	0.392	0.451	0.424	0.417	0.490	0.536	0.718	0.561	0.560
Anode Voltage	4.9	5.4	5.3	5.2	5.7	5.7	6.5	5.7	5.6
Anode Current (amps)	4.15	4.18	4.09	4.09	4.12	4.15	4.28	4.21	4.18
Ref. Cell Instant-off (volts)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.368	0.000
Conductance (mohs)	0.837	0.777	0.771	0.781	0.721	0.723	0.665	0.736	0.743
Voltage drop in ref. circuit	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.194	0.000

EVALUATION OF CATHODIC
BRIDGE PROTECTION SYSTEMS

APPENDIX A

Data spreadsheet

This spreadsheet is a compilation of the voltage and current data gathered at monthly intervals from the various cathodic protection circuits on the bridge (the Highway 87 overpass, in Big Spring, Texas).

Date:	4/26/90	11/19/90	3/28/91	5/15/91	7/31/91	8/16/91	9/10/91	10/9/91	1/7/92
Days since last reading:	99	207	129	48	77	16	25	29	90
Days since start-up (10/5/88):	651	858	987	1,035	1,112	1,128	1,153	1,182	1,272
Tester:	DE,TD	JM,DE	DE,KC	DE	DE	JM,DE	DE	DE	DE
# 1: TITANIUM MESH									
Rebar Probe (volts)	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.002
Reference Cell (volts)	0.612	0.087	0.075	0.067	0.047	0.036	0.027	0.025	0.018
Anode Voltage	6.1	6.0	6.3	6.0	5.5	5.2	5.3	5.4	5.9
Anode Current (amps)	4.86	4.83	4.86	4.80	4.84	4.82	4.80	4.81	4.85
Ref. Cell Instant-off (volts)	0.377	0.159	0.128	0.118	0.078	0.076	0.013	0.010	0.008
Conductance (mohs)	0.797	0.805	0.771	0.800	0.880	0.927	0.906	0.891	0.822
Voltage drop in ref. circuit	0.235	-0.072	-0.053	-0.051	-0.031	-0.040	0.014	0.015	0.010
# 2: TITANIUM MESH									
Rebar Probe (volts)	0.005	0.004	0.006	0.005	0.005	0.006	0.006	0.005	0.002
Reference Cell (volts)	0.777	0.822	0.986	0.893	0.768	0.595	0.654	0.732	0.975
Anode Voltage	5.3	5.3	5.6	5.2	4.8	4.3	4.5	4.6	5.1
Anode Current (amps)	3.57	3.52	3.56	3.51	3.56	3.53	3.53	3.51	3.56
Ref. Cell Instant-off (volts)	0.411	0.272	0.350	0.305	0.293	0.266	0.263	0.268	0.295
Conductance (mohs)	0.674	0.664	0.636	0.675	0.742	0.821	0.784	0.763	0.698
Voltage drop in ref. circuit	0.366	0.550	0.636	0.588	0.475	0.329	0.391	0.464	0.680
# 3: TITANIUM MESH									
Rebar Probe (volts)	0.005	0.004	0.005	0.006	0.006	0.007	0.006	0.006	0.003
Reference Cell (volts)	0.453	0.433	0.470	0.436	0.396	0.383	0.394	0.433	0.489
Anode Voltage	6.0	5.6	6.0	5.6	5.0	4.4	4.6	4.8	5.5
Anode Current (amps)	3.32	3.28	3.33	3.26	3.30	3.27	3.26	3.26	3.30
Ref. Cell Instant-off (volts)	0.327	0.277	0.344	0.319	0.302	0.286	0.282	0.300	0.329
Conductance (mohs)	0.553	0.586	0.555	0.582	0.660	0.743	0.709	0.679	0.600
Voltage drop in ref. circuit	0.126	0.156	0.126	0.117	0.094	0.097	0.112	0.133	0.160
# 4: TITANIUM MESH									
Rebar Probe (volts)	0.004	0.004	0.004	0.005	0.005	0.006	0.005	0.005	0.003
Reference Cell (volts)	0.446	0.495	0.497	0.445	0.394	0.367	0.388	0.413	0.459
Anode Voltage	6.2	6.1	6.4	6.0	5.5	5.0	5.2	5.3	5.9
Anode Current (amps)	3.93	4.66	4.95	4.83	4.90	4.87	4.86	4.85	4.91
Ref. Cell Instant-off (volts)	0.340	0.276	0.338	0.297	0.290	0.287	0.285	0.309	0.342
Conductance (mohs)	0.634	0.764	0.773	0.805	0.891	0.974	0.935	0.915	0.832
Voltage drop in ref. circuit	0.106	0.219	0.159	0.148	0.104	0.080	0.103	0.104	0.117
1-4: AVERAGE VALUES: TITANIUM MESH									
Rebar Probe (volts)	0.005	0.004	0.005	0.005	0.005	0.006	0.006	0.005	0.003
Reference Cell (volts)	0.572	0.459	0.507	0.460	0.401	0.345	0.366	0.401	0.485
Anode Voltage	5.9	5.8	6.1	5.7	5.2	4.7	4.9	5.0	5.6
Anode Current (amps)	3.92	4.07	4.18	4.10	4.15	4.12	4.11	4.11	4.16
Ref. Cell Instant-off (volts)	0.364	0.246	0.290	0.260	0.241	0.229	0.211	0.222	0.244
Conductance (mohs)	0.664	0.705	0.684	0.716	0.793	0.866	0.833	0.812	0.738
Voltage drop in ref. circuit	0.208	0.213	0.217	0.201	0.161	0.117	0.155	0.179	0.242

EVALUATION OF CATHODIC
BRIDGE PROTECTION SYSTEMS

APPENDIX A

Data spreadsheet

Date:	3/19/92	4/17/92
Days since last reading:	72	29
Days since start-up (10/5/88):	1,344	1,373
Tester:	DE	DE
# 1: TITANIUM MESH		
Rebar Probe (volts)	0.002	0.002
Reference Cell (volts)	0.019	0.022
Anode Voltage	6.2	6.1
Anode Current (amps)	4.89	4.84
Ref. Cell Instant-off (volts)	0.007	0.190
Conductance (mohs)	0.789	0.793
Voltage drop in ref. circuit	0.012	-0.168
# 2: TITANIUM MESH		
Rebar Probe (volts)	0.003	0.003
Reference Cell (volts)	1.309	1.149
Anode Voltage	5.6	5.4
Anode Current (amps)	3.60	3.56
Ref. Cell Instant-off (volts)	0.390	0.347
Conductance (mohs)	0.643	0.659
Voltage drop in ref. circuit	0.919	0.802
# 3: TITANIUM MESH		
Rebar Probe (volts)	0.003	0.004
Reference Cell (volts)	0.559	0.507
Anode Voltage	6.0	5.8
Anode Current (amps)	3.33	3.30
Ref. Cell Instant-off (volts)	0.354	0.321
Conductance (mohs)	0.555	0.569
Voltage drop in ref. circuit	0.205	0.186
# 4: TITANIUM MESH		
Rebar Probe (volts)	0.003	0.003
Reference Cell (volts)	0.508	0.472
Anode Voltage	6.2	6.0
Anode Current (amps)	4.96	4.91
Ref. Cell Instant-off (volts)	0.346	0.327
Conductance (mohs)	0.800	0.818
Voltage drop in ref. circuit	0.162	0.145
1-4: AVERAGE VALUES: TITANIUM MESH		
Rebar Probe (volts)	0.003	0.003
Reference Cell (volts)	0.599	0.538
Anode Voltage	6.0	5.8
Anode Current (amps)	4.20	4.15
Ref. Cell Instant-off (volts)	0.274	0.296
Conductance (mohs)	0.697	0.710
Voltage drop in ref. circuit	0.325	0.241

EVALUATION OF CATHODIC BRIDGE PROTECTION SYSTEMS

APPENDIX A

Data spreadsheet

Client: Texas Department of Transportation
Mr. Bill Burnett, Project Coordinator

Performed at: The College of Engineering,
Texas Tech University,
Lubbock, Texas

Faculty: Harry W. Parker, Ph.D, P.E.
Phil Nash, P.E.

Research Assistant: Robert W. Feingold

Date:	10/28/88	10/28/88	12/13/88	12/15/88	1/31/89	2/1/89	2/2/89	3/13/89	4/13/89
Days since last reading:	23	23	46	2	47	1	1	152	31
Days since start-up (10/5/88):	23	23	69	71	118	119	120	272	303
Tester:	Corrpro	Corrpro	Corrpro	Corrpro	Corrpro	Corrpro	Corrpro	MC,DR,DE	DR,DE,TD
# 5: CONDUCTIVE POLYMER CABLE									
Rebar Probe (volts)	-0.00625	0.00015	0.004	0.004	0.004	0.005	0.003	0.006	0.007
Reference Cell (volts)	0.352	0.837	1.092	0.978	1.055	0.521	0.901	1.001	1.053
Anode Voltage	0.45	13.79	11.4	10.2	10.0	6.4	9.3	8.9	9.6
Anode Current (amps)	0.00	5.80	5.98	5.01	4.97	4.88	4.91	4.97	4.99
Ref. Cell Instant-off (volts)		0.470	0.679	0.612	0.636	0.420	0.570		
Conductance (mohs)		0.421	0.525	0.491	0.497	0.763	0.528	0.558	0.520
Voltage drop in ref. circuit		0.367	0.413	0.366	0.419	0.101	0.331		
# 6: CONDUCTIVE POLYMER CABLE									
Rebar Probe (volts)	-0.00104	0.00101	0.005	0.004	0.003	0.002	0.007	0.003	0.001
Reference Cell (volts)	0.335	0.644	0.751	0.758	0.822	0.372	0.692	0.743	0.867
Anode Voltage	0.15	13.63	10.7	10.4	9.8	6.5	9.3	9.1	10.1
Anode Current (amps)	0.00	5.80	5.92	5.50	5.45	5.32	5.34	5.43	5.45
Ref. Cell Instant-off (volts)		0.479	0.597	0.558	0.596	0.337	0.499		
Conductance (mohs)		0.426	0.553	0.529	0.556	0.818	0.574	0.597	0.540
Voltage drop in ref. circuit		0.165	0.154	0.200	0.226	0.035	0.193		
# 7: CONDUCTIVE POLYMER CABLE									
Rebar Probe (volts)	-0.00197	0.00202	0.005	0.004	0.006	0.006	0.005	0.007	0.006
Reference Cell (volts)	0.302	0.518	0.773	0.628	0.734	0.482	0.666	0.613	0.760
Anode Voltage	0.19	13.30	10.9	11.2	10.4	6.8	9.6	9.7	9.8
Anode Current (amps)	0.00	5.00	5.09	4.71	4.67	4.78	4.81	4.89	4.91
Ref. Cell Instant-off (volts)		0.399	0.573	0.479	0.520	0.388	0.482		
Conductance (mohs)		0.376	0.467	0.421	0.449	0.703	0.501	0.504	0.501
Voltage drop in ref. circuit		0.119	0.200	0.149	0.214	0.094	0.184		
# 8: CONDUCTIVE POLYMER CABLE									
Rebar Probe (volts)	-0.00175	0.00212	0.005	0.004	0.006	0.005	0.003	0.006	0.005
Reference Cell (volts)	0.323	0.587	0.926	0.825	0.840	0.577	0.710	0.852	0.849
Anode Voltage	0.17	14.77	10.3	11.0	9.7	6.7	9.0	9.2	9.1
Anode Current (amps)	0.00	4.80	5.93	5.51	5.46	5.56	5.61	5.68	5.70
Ref. Cell Instant-off (volts)		0.410	0.618	0.545	0.563	0.451	0.506		
Conductance (mohs)		0.325	0.576	0.501	0.563	0.830	0.623	0.617	0.626
Voltage drop in ref. circuit		0.177	0.308	0.280	0.277	0.126	0.204		
5-8: AVERAGE VALUES: POLYMER CABLE									
Rebar Probe (volts)	-0.003	0.001	0.005	0.004	0.005	0.005	0.005	0.006	0.005
Reference Cell (volts)	0.328	0.647	0.886	0.797	0.863	0.488	0.742	0.802	0.882
Anode Voltage	0.2	13.9	10.8	10.7	10.0	6.6	9.3	9.2	9.7
Anode Current (amps)	0.00	5.35	5.73	5.18	5.14	5.14	5.17	5.24	5.26
Ref. Cell Instant-off (volts)		0.440	0.617	0.549	0.579	0.399	0.514		
Conductance (mohs)		0.387	0.530	0.485	0.516	0.778	0.557	0.569	0.547
Voltage drop in ref. circuit		0.207	0.269	0.249	0.284	0.089	0.228		

EVALUATION OF CATHODIC
BRIDGE PROTECTION SYSTEMS

APPENDIX A

Data spreadsheet

Key to tester names:
MC - Mike Chetty
DR - Dan Richardson
DE - David Elmore
TD - Todd Darden
JM - John Moore
KC - Ken Corse

Date:	5/26/89	6/13/89	7/17/89	8/18/89	9/19/89	10/31/89	11/28/89	1/9/90	1/17/90
Days since last reading:	43	18	34	32	32	42	28	12	8
Days since start-up (10/5/88):	346	364	398	430	462	504	532	544	552
Tester:	DR	JM,DR	DR,KC	DR	DR	DR	DR	DR,DE	DR
# 5: CONDUCTIVE POLYMER CABLE									
Rebar Probe (volts)	0.008	0.005	0.008	0.010	0.005	0.005	0.003	0.005	0.007
Reference Cell (volts)	0.432	1.163	0.808	0.509	1.225	1.002	1.366	0.781	0.819
Anode Voltage	6.0	9.4	8.1	6.8	10.4	9.9	12.8	8.7	8.8
Anode Current (amps)	4.89	4.92	4.84	4.84	4.87	4.89	5.03	4.95	4.91
Ref. Cell Instant-off (volts)								0.434	
Conductance (mohs)	0.815	0.523	0.598	0.712	0.468	0.494	0.393	0.569	0.558
Voltage drop in ref. circuit								0.347	
# 6: CONDUCTIVE POLYMER CABLE									
Rebar Probe (volts)	0.005	0.002	0.006	0.008	0.002	0.003	0.002	0.003	0.005
Reference Cell (volts)	0.395	0.823	0.681	0.467	0.967	0.888	1.393	0.756	0.803
Anode Voltage	6.1	9.1	8.0	6.9	10.1	9.6	12.7	9.0	9.2
Anode Current (amps)	5.36	5.40	5.29	5.30	5.33	5.35	5.48	5.42	5.38
Ref. Cell Instant-off (volts)								0.422	
Conductance (mohs)	0.879	0.593	0.661	0.768	0.528	0.557	0.431	0.602	0.585
Voltage drop in ref. circuit								0.334	
# 7: CONDUCTIVE POLYMER CABLE									
Rebar Probe (volts)	0.008	0.006	0.007	0.007	0.004	0.003	0.002	0.002	0.004
Reference Cell (volts)	0.439	0.645	0.554	0.492	0.691	0.668	0.870	0.552	0.433
Anode Voltage	5.8	9.8	8.4	7.2	11.4	11.4	17.2	10.5	10.6
Anode Current (amps)	4.80	4.85	4.75	4.76	4.79	4.81	4.93	4.89	4.85
Ref. Cell Instant-off (volts)								0.389	
Conductance (mohs)	0.828	0.495	0.565	0.661	0.420	0.422	0.287	0.466	0.458
Voltage drop in ref. circuit								0.163	
# 8: CONDUCTIVE POLYMER CABLE									
Rebar Probe (volts)	0.008	0.006	0.009	0.008	0.004	0.004	0.003	0.003	0.004
Reference Cell (volts)	0.545	0.940	0.871	0.695	1.014	1.009	1.551	0.669	0.630
Anode Voltage	5.7	9.5	8.5	7.1	10.7	10.1	14.8	9.1	8.7
Anode Current (amps)	5.60	5.65	5.57	5.59	5.62	5.64	5.73	5.69	5.65
Ref. Cell Instant-off (volts)								0.419	
Conductance (mohs)	0.982	0.595	0.655	0.787	0.525	0.558	0.387	0.625	0.649
Voltage drop in ref. circuit								0.250	
5-8: AVERAGE VALUES: POLYMER CABLE									
Rebar Probe (volts)	0.007	0.005	0.008	0.008	0.004	0.004	0.003	0.003	0.005
Reference Cell (volts)	0.453	0.893	0.729	0.541	0.974	0.892	1.295	0.690	0.671
Anode Voltage	5.9	9.5	8.3	7.0	10.7	10.3	14.4	9.3	9.3
Anode Current (amps)	5.16	5.21	5.11	5.12	5.15	5.17	5.29	5.24	5.20
Ref. Cell Instant-off (volts)								0.416	
Conductance (mohs)	0.876	0.552	0.620	0.732	0.485	0.508	0.375	0.566	0.562
Voltage drop in ref. circuit								0.274	

EVALUATION OF CATHODIC
BRIDGE PROTECTION SYSTEMS

APPENDIX A

Data spreadsheet

This spreadsheet is a compilation of the voltage and current data gathered at monthly intervals from the various cathodic protection circuits on the bridge (the Highway 87 overpass, in Big Spring, Texas).

Date:	4/26/90	11/19/90	3/28/91	5/15/91	7/31/91	8/16/91	9/10/91	10/9/91	1/7/92
Days since last reading:	99	207	129	48	77	16	25	29	90
Days since start-up (10/5/88):	651	858	987	1,035	1,112	1,128	1,153	1,182	1,272
Tester:	DE,TD	JM,DE	DE,KC	DE	DE	JM,DE	DE	DE	DE
# 5: CONDUCTIVE POLYMER CABLE									
Rebar Probe (volts)	0.006	0.004	0.004	0.003	0.003	0.004	0.004	0.003	0.001
Reference Cell (volts)	1.131	0.994	1.066	0.420	0.030	0.037	0.024	0.020	0.025
Anode Voltage	12.1	14.4	23.5	24.1	24.1	25.5	25.5	25.2	25.0
Anode Current (amps)	4.90	4.96	4.06	1.66	0.04	0.01	0.01	0.01	0.00
Ref. Cell Instant-off (volts)	0.528	0.269	0.464	0.262	0.029	0.037	0.021	0.019	0.023
Conductance (mohs)	0.405	0.344	0.173	0.069	0.002	0.000	0.000	0.000	0.000
Voltage drop in ref. circuit	0.603	0.725	0.602	0.158	0.001	0.000	0.003	0.001	0.002
# 6: CONDUCTIVE POLYMER CABLE									
Rebar Probe (volts)	0.003	0.004	0.004	0.003	0.003	0.003	0.003	0.002	0.000
Reference Cell (volts)	0.998	0.768	0.752	0.125	0.044	0.043	0.033	0.030	0.028
Anode Voltage	11.5	15.7	23.4	24.2	25.1	25.0	25.3	25.2	25.5
Anode Current (amps)	5.38	5.36	4.82	1.55	0.07	0.08	0.02	0.01	0.01
Ref. Cell Instant-off (volts)	0.429	0.268	0.354	0.120	0.044	0.042	0.031	0.029	0.028
Conductance (mohs)	0.468	0.341	0.206	0.064	0.003	0.003	0.001	0.000	0.000
Voltage drop in ref. circuit	0.569	0.500	0.398	0.005	0.000	0.001	0.002	0.001	0.000
# 7: CONDUCTIVE POLYMER CABLE									
Rebar Probe (volts)	0.003	0.002	0.003	0.003	0.003	0.004	0.003	0.003	0.001
Reference Cell (volts)	0.647	0.110	0.066	0.064	0.095	0.101	0.100	0.091	0.078
Anode Voltage	13.0	23.6	23.7	24.0	24.8	24.8	24.8	25.0	24.9
Anode Current (amps)	4.85	3.58	1.88	1.65	0.01	0.01	0.01	0.01	0.00
Ref. Cell Instant-off (volts)	0.419	0.275	0.062	0.062	0.098	0.101	0.099	0.091	0.079
Conductance (mohs)	0.373	0.152	0.079	0.069	0.000	0.000	0.000	0.000	0.000
Voltage drop in ref. circuit	0.228	-0.165	0.004	0.002	-0.003	0.000	0.001	0.000	-0.001
# 8: CONDUCTIVE POLYMER CABLE									
Rebar Probe (volts)	0.003	0.003	0.004	0.005	0.004	0.004	0.004	0.004	0.001
Reference Cell (volts)	0.790	0.790	1.252	0.780	0.208	0.138	0.181	0.178	0.172
Anode Voltage	10.7	12.4	21.1	23.9	24.7	24.9	25.0	24.8	24.5
Anode Current (amps)	5.65	5.66	5.66	3.53	0.43	0.24	0.14	0.07	0.06
Ref. Cell Instant-off (volts)	0.416	0.433	0.547	0.404	0.186	0.134	0.168	0.168	0.161
Conductance (mohs)	0.528	0.456	0.268	0.148	0.017	0.010	0.006	0.003	0.002
Voltage drop in ref. circuit	0.374	0.357	0.705	0.376	0.022	0.004	0.013	0.010	0.011
5-8: AVERAGE VALUES: POLYMER CABLE									
Rebar Probe (volts)	0.004	0.003	0.004	0.004	0.003	0.004	0.004	0.003	0.001
Reference Cell (volts)	0.892	0.666	0.784	0.347	0.094	0.080	0.085	0.080	0.076
Anode Voltage	11.8	16.5	22.9	24.1	24.7	25.1	25.2	25.1	25.0
Anode Current (amps)	5.20	4.89	4.11	2.10	0.14	0.08	0.05	0.03	0.02
Ref. Cell Instant-off (volts)	0.448	0.311	0.357	0.212	0.089	0.079	0.080	0.077	0.073
Conductance (mohs)	0.443	0.323	0.182	0.087	0.006	0.003	0.002	0.001	0.001
Voltage drop in ref. circuit	0.444	0.354	0.427	0.135	0.005	0.001	0.005	0.003	0.003

EVALUATION OF CATHODIC
BRIDGE PROTECTION SYSTEMS

APPENDIX A

Data spreadsheet

Date:	3/19/92	4/17/92
Days since last reading:	72	29
Days since start-up (10/5/88):	1,344	1,373
Tester:	DE	DE
# 5: CONDUCTIVE POLYMER CABLE		
Rebar Probe (volts)	0.002	0.002
Reference Cell (volts)	0.013	0.013
Anode Voltage	25.0	25.2
Anode Current (amps)	0.01	0.01
Ref. Cell Instant-off (volts)	0.013	0.011
Conductance (mohs)	0.000	0.000
Voltage drop in ref. circuit	0.000	0.002
# 6: CONDUCTIVE POLYMER CABLE		
Rebar Probe (volts)	0.001	0.001
Reference Cell (volts)	0.042	0.047
Anode Voltage	25.8	25.8
Anode Current (amps)	0.01	0.01
Ref. Cell Instant-off (volts)	0.042	0.045
Conductance (mohs)	0.000	0.000
Voltage drop in ref. circuit	0.000	0.002
# 7: CONDUCTIVE POLYMER CABLE		
Rebar Probe (volts)	0.001	0.001
Reference Cell (volts)	0.069	0.081
Anode Voltage	25.0	25.2
Anode Current (amps)	0.01	0.01
Ref. Cell Instant-off (volts)	0.070	0.080
Conductance (mohs)	0.000	0.000
Voltage drop in ref. circuit	-0.001	0.001
# 8: CONDUCTIVE POLYMER CABLE		
Rebar Probe (volts)	0.002	0.002
Reference Cell (volts)	0.114	0.101
Anode Voltage	24.8	24.7
Anode Current (amps)	0.05	0.04
Ref. Cell Instant-off (volts)	0.107	0.094
Conductance (mohs)	0.002	0.002
Voltage drop in ref. circuit	0.007	0.007
5-8: AVERAGE VALUES: POLYMER CABLE		
Rebar Probe (volts)	0.002	0.002
Reference Cell (volts)	0.060	0.061
Anode Voltage	25.2	25.2
Anode Current (amps)	0.02	0.02
Ref. Cell Instant-off (volts)	0.058	0.058
Conductance (mohs)	0.001	0.001
Voltage drop in ref. circuit	0.002	0.003

EVALUATION OF CATHODIC
BRIDGE PROTECTION SYSTEMS

APPENDIX A

Data spreadsheet

Client: Texas Department of Transportation
Mr. Bill Burnett, Project Coordinator

Performed at: The College of Engineering,
Texas Tech University,
Lubbock, Texas

Faculty: Harry W. Parker, Ph.D, P.E.
Phil Nash, P.E.

Research Assistant: Robert W. Feingold

Date:	10/28/88	10/28/88	12/13/88	12/15/88	1/31/89	2/1/89	2/2/89	3/13/89	4/13/89
Days since last reading:	23	23	46	2	47	1	1	152	31
Days since start-up (10/5/88):	23	23	69	71	118	119	120	272	303
Tester:	Corrpro	Corrpro	Corrpro	Corrpro	Corrpro	Corrpro	Corrpro	MC,DR,DE	DR,DE,TD
# 9: CARBON FIBER									
Rebar Probe (volts)	-0.00961	0.00105	0.005	0.004	0.004	0.003	0.005	0.004	0.004
Reference Cell (volts)	0.299	0.490	0.551	0.536	0.522	0.406	0.475	0.459	0.544
Anode Voltage	0.24	2.99	4.1	3.5	3.6	2.7	3.4	3.3	3.8
Anode Current (amps)	0.00	4.50	4.46	4.20	4.13	4.26	4.29	4.37	4.38
Ref. Cell Instant-off (volts)		0.397	0.430	0.426	0.411	0.351	0.387		
Conductance (mohs)		1.505	1.088	1.200	1.147	1.578	1.262	1.324	1.153
Voltage drop in ref. circuit		0.093	0.121	0.110	0.111	0.055	0.088		
# 10: CARBON FIBER									
Rebar Probe (volts)	-0.00296	0.00215	0.004	0.004	0.005	0.005	0.005	0.006	0.005
Reference Cell (volts)	0.280	0.429	0.515	0.487	0.511	0.379	0.463	0.447	0.485
Anode Voltage	0.24	3.51	5.4	4.9	5.0	3.6	4.5	4.4	5.4
Anode Current (amps)	0.00	6.00	6.17	6.03	5.96	6.07	6.13	6.24	6.26
Ref. Cell Instant-off (volts)		0.355	0.423	0.404	0.434	0.325	0.395		
Conductance (mohs)		1.709	1.143	1.231	1.192	1.686	1.362	1.418	1.159
Voltage drop in ref. circuit		0.074	0.092	0.083	0.077	0.054	0.068		
9-10: AVERAGE VALUES: CARBON FIBER									
Rebar Probe (volts)	-0.003	0.002	0.005	0.004	0.005	0.004	0.005	0.005	0.005
Reference Cell (volts)	0.145	0.460	0.533	0.512	0.517	0.393	0.469	0.453	0.515
Anode Voltage	0.1	3.3	4.8	4.2	4.3	3.2	4.0	3.9	4.6
Anode Current (amps)	0.00	5.25	5.32	5.12	5.05	5.17	5.21	5.31	5.32
Ref. Cell Instant-off (volts)		0.376	0.427	0.415	0.423	0.338	0.391		
Conductance (mohs)		1.607	1.115	1.215	1.170	1.632	1.312	1.371	1.156
Voltage drop in ref. circuit		0.083	0.107	0.097	0.094	0.055	0.078		

EVALUATION OF CATHODIC
BRIDGE PROTECTION SYSTEMS

APPENDIX A

Data spreadsheet

Key to tester names:
MC - Mike Chetty
DR - Dan Richardson
DE - David Elmore
TD - Todd Darden
JM - John Moore
KC - Ken Corse

Date:	5/26/89	6/13/89	7/17/89	8/18/89	9/19/89	10/31/89	11/28/89	1/9/90	1/17/90
Days since last reading:	43	18	34	32	32	42	28	12	8
Days since start-up (10/5/88):	346	364	398	430	462	504	532	544	552
Tester:	DR	JM,DR	DR,KC	DR	DR	DR	DR	DR,DE	DR
# 9: CARBON FIBER									
Rebar Probe (volts)	0.003	0.005	0.007	0.007	0.006	0.005	0.004	0.004	0.005
Reference Cell (volts)	0.358	0.453	0.410	0.391	0.523	0.585	0.915	0.604	0.608
Anode Voltage	2.7	3.3	3.1	2.9	3.5	3.7	4.6	3.6	3.6
Anode Current (amps)	4.28	4.32	4.21	4.22	4.25	4.26	4.40	4.34	4.29
Ref. Cell Instant-off (volts)								0.362	
Conductance (mohs)	1.585	1.309	1.358	1.455	1.214	1.151	0.957	1.206	1.192
Voltage drop in ref. circuit								0.242	
# 10: CARBON FIBER									
Rebar Probe (volts)	0.006	0.006	0.008	0.008	0.005	0.005	0.004	0.004	0.005
Reference Cell (volts)	0.350	0.416	0.374	0.373	0.423	0.474	0.598	0.507	0.498
Anode Voltage	3.5	4.4	4.0	3.8	5.1	5.4	7.9	5.1	5.1
Anode Current (amps)	6.13	6.19	6.04	6.06	6.10	6.13	6.26	6.21	6.17
Ref. Cell Instant-off (volts)								0.348	
Conductance (mohs)	1.751	1.407	1.510	1.595	1.196	1.135	0.792	1.218	1.210
Voltage drop in ref. circuit								0.159	
9-10: AVERAGE VALUES: CARBON FIBER									
Rebar Probe (volts)	0.005	0.006	0.008	0.008	0.006	0.005	0.004	0.004	0.005
Reference Cell (volts)	0.354	0.435	0.392	0.382	0.473	0.530	0.757	0.556	0.553
Anode Voltage	3.1	3.9	3.6	3.4	4.3	4.6	6.3	4.4	4.4
Anode Current (amps)	5.21	5.26	5.13	5.14	5.18	5.20	5.33	5.28	5.23
Ref. Cell Instant-off (volts)								0.355	
Conductance (mohs)	1.668	1.358	1.434	1.525	1.205	1.143	0.874	1.212	1.201
Voltage drop in ref. circuit								0.201	

EVALUATION OF CATHODIC
BRIDGE PROTECTION SYSTEMS

APPENDIX A

Data spreadsheet

This spreadsheet is a compilation of the voltage and current data gathered at monthly intervals from the various cathodic protection circuits on the bridge (the Highway 87 overpass, in Big Spring, Texas).

Date:	4/26/90	11/19/90	3/28/91	5/15/91	7/31/91	8/16/91	9/10/91	10/9/91	1/7/92
Days since last reading:	99	207	129	48	77	16	25	29	90
Days since start-up (10/5/88):	651	858	987	1,035	1,112	1,128	1,153	1,182	1,272
Tester:	DE,TD	JM,DE	DE,KC	DE	DE	JM,DE	DE	DE	DE
# 9: CARBON FIBER									
Rebar Probe (volts)	0.005	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.001
Reference Cell (volts)	0.624	0.700	0.808	0.723	0.691	0.508	0.602	0.696	0.992
Anode Voltage	3.7	3.8	4.1	3.8	3.7	3.1	3.3	3.5	4.2
Anode Current (amps)	4.29	4.13	4.11	4.02	4.28	4.25	4.24	4.23	4.29
Ref. Cell Instant-off (volts)	0.349	0.332	0.336	0.305	0.304	0.245	0.253	0.272	0.326
Conductance (mohs)	1.159	1.087	1.002	1.058	1.157	1.371	1.285	1.209	1.021
Voltage drop in ref. circuit	0.275	0.368	0.472	0.418	0.387	0.263	0.349	0.424	0.666
# 10: CARBON FIBER									
Rebar Probe (volts)	0.005	0.003	0.003	0.005	0.005	0.005	0.004	0.004	0.002
Reference Cell (volts)	0.453	0.496	0.404	0.384	0.363	0.330	0.357	0.328	0.160
Anode Voltage	5.6	5.5	6.5	6.3	5.7	4.4	5.0	5.4	7.3
Anode Current (amps)	6.13	6.00	6.15	6.06	6.13	6.09	6.06	6.06	6.13
Ref. Cell Instant-off (volts)	0.305	0.294	0.290	0.265	0.253	0.235	0.186	0.163	0.068
Conductance (mohs)	1.095	1.091	0.946	0.962	1.075	1.384	1.212	1.122	0.840
Voltage drop in ref. circuit	0.148	0.202	0.114	0.119	0.110	0.095	0.171	0.165	0.092
9-10: AVERAGE VALUES: CARBON FIBER									
Rebar Probe (volts)	0.005	0.004	0.004	0.005	0.005	0.005	0.004	0.004	0.002
Reference Cell (volts)	0.539	0.598	0.606	0.554	0.527	0.419	0.480	0.512	0.576
Anode Voltage	4.7	4.7	5.3	5.1	4.7	3.8	4.2	4.5	5.8
Anode Current (amps)	5.21	5.07	5.13	5.04	5.21	5.17	5.15	5.15	5.21
Ref. Cell Instant-off (volts)	0.327	0.313	0.313	0.285	0.279	0.240	0.220	0.218	0.197
Conductance (mohs)	1.127	1.089	0.974	1.010	1.116	1.378	1.248	1.165	0.931
Voltage drop in ref. circuit	0.212	0.285	0.293	0.269	0.248	0.179	0.260	0.295	0.379

EVALUATION OF CATHODIC
BRIDGE PROTECTION SYSTEMS

APPENDIX A

Data spreadsheet

Client: Texas Department of Transportation
Mr. Bill Burnett, Project Coordinator

Performed at: The College of Engineering,
Texas Tech University,
Lubbock, Texas

Faculty: Harry W. Parker, Ph.D, P.E.
Phil Nash, P.E.

Research Assistant: Robert W. Feingold

Date:	10/28/88	10/28/88	12/13/88	12/15/88	1/31/89	2/1/89	2/2/89	3/13/89	4/13/89
Days since last reading:	23	23	46	2	47	1	1	152	31
Days since start-up (10/5/88):	23	23	69	71	118	119	120	272	303
Tester:	Corrpro	Corrpro	Corrpro	Corrpro	Corrpro	Corrpro	Corrpro	MC,DR,DE	DR,DE,TD
# 11: HOT-SPRAYED ZINC									
Rebar Probe (volts)	-0.01225	-0.00290	-0.003	0.010	-0.002	-0.012	-0.010	-0.012	0.002
Reference Cell (volts)	0.271	1.420	0.364	0.700	0.451	0.311	0.318	0.276	0.530
Anode Voltage	-0.23	5.62	1.9	2.4	9.2	9.7	19.5	25.1	6.9
Anode Current (amps)	0.00	0.35	0.44	0.38	0.36	0.36	0.42	0.40	0.48
Ref. Cell Instant-off (volts)		0.572	0.485	0.490	0.359	0.312	0.311		
Conductance (mohs)		0.062	0.232	0.158	0.039	0.037	0.022	0.016	0.070
Voltage drop in ref. circuit		0.848	-0.121	0.210	0.092	-0.001	0.007		
# 12: HOT-SPRAYED ZINC									
Rebar Probe (volts)	-0.00845	0.04550	0.0085	0.041	0.010	0.006	0.008	0.004	0.006
Reference Cell (volts)	0.255	1.220	*OOS*	*OOS*	0.661	0.353	0.337	0.327	0.708
Anode Voltage	-0.15	10.95	17.7	7.2	24.8	15.8	24.9	25.1	24.4
Anode Current (amps)	0.00	0.90	0.98	0.33	0.22	0.32	0.25	0.20	0.36
Ref. Cell Instant-off (volts)		0.570	1.194	0.971	0.530	0.328	0.317		
Conductance (mohs)		0.082	0.055	0.046	0.009	0.020	0.010	0.008	0.015
Voltage drop in ref. circuit		0.650			0.131	0.025	0.020		
# 13: HOT-SPRAYED ZINC									
Rebar Probe (volts)	-0.00693	0.00425	0.010	0.011	0.011	0.011	0.015	0.012	0.008
Reference Cell (volts)	0.361	2.140	0.815	0.758	0.774	0.653	0.675	0.652	0.767
Anode Voltage	-0.24	13.46	2.5	2.1	4.7	2.5	4.1	6.1	2.6
Anode Current (amps)	0.00	0.85	0.86	0.49	0.47	0.45	0.46	0.53	0.54
Ref. Cell Instant-off (volts)		0.830	0.680	0.624	0.673	0.569	0.596		
Conductance (mohs)		0.063	0.344	0.233	0.100	0.180	0.112	0.087	0.208
Voltage drop in ref. circuit		1.310	0.135	0.134	0.101	0.084	0.079		
# 14: HOT-SPRAYED ZINC									
Rebar Probe (volts)	-0.00848	0.03010	0.034	0.016	0.011	0.028	0.015	0.018	0.021
Reference Cell (volts)	0.297	2.730	1.464	0.926	0.676	0.864	0.752	0.814	1.456
Anode Voltage	-0.36	6.39	7.8	2.4	5.1	3.0	5.6	7.5	12.1
Anode Current (amps)	0.00	0.15	0.25	0.08	0.11	0.13	0.15	0.22	0.24
Ref. Cell Instant-off (volts)		0.610	0.797	0.499	0.500	0.554	0.536		
Conductance (mohs)		0.023	0.032	0.033	0.022	0.043	0.027	0.029	0.020
Voltage drop in ref. circuit		2.120	0.667	0.427	0.176	0.310	0.216		
# 15: HOT-SPRAYED ZINC									
Rebar Probe (volts)	-0.01489	0.00620	0.011	0.011	0.006	0.002	0.000	0.010	0.008
Reference Cell (volts)	0.295	1.290	1.030	0.712	0.523	0.349	0.315	0.468	0.547
Anode Voltage	-0.23	3.81	2.4	1.5	2.1	0.8	0.9	4.2	4.0
Anode Current (amps)	0.00	0.25	0.33	0.24	0.25	0.41	0.45	0.51	0.52
Ref. Cell Instant-off (volts)		0.540	0.559	0.491	0.405	0.289	0.285		
Conductance (mohs)		0.066	0.138	0.160	0.119	0.513	0.500	0.121	0.130
Voltage drop in ref. circuit		0.750	0.471	0.221	0.118	0.060	0.030		

EVALUATION OF CATHODIC
BRIDGE PROTECTION SYSTEMS

APPENDIX A

Data spreadsheet

Key to tester names:
MC - Mike Chetty
DR - Dan Richardson
DE - David Elmore
TD - Todd Darden
JM - John Moore
KC - Ken Corse

Date:	5/26/89	6/13/89	7/17/89	8/18/89	9/19/89	10/31/89	11/28/89	1/9/90	1/17/90
Days since last reading:	43	18	34	32	32	42	28	12	8
Days since start-up (10/5/88):	346	364	398	430	462	504	532	544	552
Tester:	DR	JM,DR	DR,KC	DR	DR	DR	DR	DR,DE	DR
# 11: HOT-SPRAYED ZINC									
Rebar Probe (volts)	-0.009	-0.004	-0.001	-0.001	0.000	-0.001	-0.001	0.000	0.001
Reference Cell (volts)	0.257	0.311	0.297	0.302	0.299	0.307	0.307	0.306	0.314
Anode Voltage	25.8	25.3	25.3	25.4	25.5	26.0	27.1	26.4	26.2
Anode Current (amps)	0.08	0.15	0.12	0.12	0.05	0.10	0.04	0.03	0.06
Ref. Cell Instant-off (volts)								0.296	
Conductance (mohs)	0.003	0.006	0.005	0.005	0.002	0.004	0.001	0.001	0.002
Voltage drop in ref. circuit								0.010	
# 12: HOT-SPRAYED ZINC									
Rebar Probe (volts)	0.005	0.003	0.005	0.005	0.003	0.002	0.001	0.002	0.003
Reference Cell (volts)	0.244	0.252	0.220	0.274	0.301	0.199	0.237	0.277	0.188
Anode Voltage	25.0	24.3	24.2	24.1	24.6	24.8	25.2	25.3	25.0
Anode Current (amps)	0.08	0.11	0.06	0.04	0.02	0.09	0.02	0.03	0.04
Ref. Cell Instant-off (volts)								0.303	
Conductance (mohs)	0.003	0.005	0.002	0.002	0.001	0.004	0.001	0.001	0.002
Voltage drop in ref. circuit								-0.026	
# 13: HOT-SPRAYED ZINC									
Rebar Probe (volts)	0.000	0.001	0.004	0.003	0.001	0.001	0.001	-0.001	0.001
Reference Cell (volts)	0.478	0.468	0.504	0.556	0.595	0.509	0.499	0.572	0.507
Anode Voltage	25.6	23.1	25.3	25.4	25.6	25.5	27.4	26.0	25.5
Anode Current (amps)	0.40	0.57	0.15	0.08	0.03	0.09	0.36	0.21	0.07
Ref. Cell Instant-off (volts)								0.634	
Conductance (mohs)	0.016	0.025	0.006	0.003	0.001	0.004	0.013	0.008	0.003
Voltage drop in ref. circuit								-0.062	
# 14: HOT-SPRAYED ZINC									
Rebar Probe (volts)	0.012	0.013	0.013	0.005	0.004	0.003	0.001	0.002	0.005
Reference Cell (volts)	0.759	1.378	1.148	0.812	0.872	0.412	0.205	0.372	0.900
Anode Voltage	23.4	20.2	13.6	22.2	50.1	52.1	56.3	52.6	52.0
Anode Current (amps)	0.18	0.22	0.10	0.15	0.23	0.21	0.19	0.14	0.17
Ref. Cell Instant-off (volts)								0.320	
Conductance (mohs)	0.008	0.011	0.007	0.007	0.005	0.004	0.003	0.003	0.003
Voltage drop in ref. circuit								0.052	
# 15: HOT-SPRAYED ZINC									
Rebar Probe (volts)	-0.004	-0.002	0.002	0.001	-0.001	-0.001	-0.001	-0.002	-0.001
Reference Cell (volts)	0.276	0.284	0.282	0.285	0.273	0.270	0.220	0.258	0.265
Anode Voltage	51.1	45.7	49.3	49.2	49.5	50.3	53.9	51.7	51.0
Anode Current (amps)	0.45	0.50	0.17	0.10	0.20	0.29	0.63	0.16	0.09
Ref. Cell Instant-off (volts)								0.259	
Conductance (mohs)	0.009	0.011	0.003	0.002	0.004	0.006	0.012	0.003	0.002
Voltage drop in ref. circuit								-0.001	

EVALUATION OF CATHODIC
BRIDGE PROTECTION SYSTEMS

APPENDIX A

Data spreadsheet

This spreadsheet is a compilation of the voltage and current data gathered at monthly intervals from the various cathodic protection circuits on the bridge (the Highway 87 overpass, in Big Spring, Texas).

Date:	4/26/90	11/19/90	3/28/91	5/15/91	7/31/91	8/16/91	9/10/91	10/9/91	1/7/92
Days since last reading:	99	207	129	48	77	16	25	29	90
Days since start-up (10/5/88):	651	858	987	1,035	1,112	1,128	1,153	1,182	1,272
Tester:	DE,TD	JM,DE	DE,KC	DE	DE	JM,DE	DE	DE	DE
# 11: HOT-SPRAYED ZINC									
Rebar Probe (volts)	0.000	0.001	0.002	0.003	0.003	0.003	0.003	0.003	0.001
Reference Cell (volts)	0.300	0.282	0.289	0.268	0.253	0.263	0.247	0.245	0.263
Anode Voltage	25.7	25.2	25.7	25.4	25.0	24.8	25.4	25.6	25.5
Anode Current (amps)	0.14	0.35	0.05	0.03	0.02	0.03	0.00	0.01	0.02
Ref. Cell Instant-off (volts)	0.299	0.276	0.287	0.270	0.259	0.267	0.246	0.243	0.263
Conductance (mohs)	0.005	0.014	0.002	0.001	0.001	0.001	0.000	0.000	0.001
Voltage drop in ref. circuit	0.001	0.006	0.002	-0.002	-0.006	-0.004	0.001	0.002	0.000
# 12: HOT-SPRAYED ZINC									
Rebar Probe (volts)	0.002	0.002	0.002	0.004	0.003	0.004	0.003	0.003	0.001
Reference Cell (volts)	0.179	0.229	0.232	0.184	0.224	0.144	0.215	0.162	0.233
Anode Voltage	24.8	25.1	0.5	25.2	25.2	25.1	25.5	25.2	25.2
Anode Current (amps)	0.05	2.28	0.00	0.03	0.01	0.01	0.01	0.01	0.01
Ref. Cell Instant-off (volts)	0.172	0.172	0.227	0.175	0.226	0.140	0.215	0.123	0.189
Conductance (mohs)	0.002	0.091	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Voltage drop in ref. circuit	0.007	0.057	0.005	0.009	-0.002	0.004	0.000	0.039	0.044
# 13: HOT-SPRAYED ZINC									
Rebar Probe (volts)	-0.002	-0.002	0.000	0.001	0.002	0.001	-0.001	0.000	0.001
Reference Cell (volts)	0.482	0.585	0.549	0.460	0.544	0.471	0.545	0.513	0.600
Anode Voltage	25.3	25.9	26.5	26.5	26.2	25.3	26.2	26.4	26.1
Anode Current (amps)	0.14	1.22	0.04	0.03	0.01	0.02	0.01	0.01	0.01
Ref. Cell Instant-off (volts)	0.493	0.564	0.547	0.478	0.546	0.478	0.545	0.489	0.547
Conductance (mohs)	0.006	0.047	0.002	0.001	0.000	0.001	0.000	0.000	0.000
Voltage drop in ref. circuit	-0.011	0.021	0.002	-0.018	-0.002	-0.007	0.000	0.024	0.053
# 14: HOT-SPRAYED ZINC									
Rebar Probe (volts)	0.004	0.002	0.002	0.003	0.003	0.004	0.003	0.003	0.000
Reference Cell (volts)	0.350	0.217	0.289	0.277	0.237	0.245	0.248	0.248	0.293
Anode Voltage	50.8	50.5	51.2	50.2	49.6	49.4	50.2	50.6	49.8
Anode Current (amps)	0.27	1.47	0.70	0.20	0.06	0.09	0.05	0.03	0.05
Ref. Cell Instant-off (volts)	0.340	0.212	0.290	0.276	0.241	0.245	0.235	0.247	0.311
Conductance (mohs)	0.005	0.029	0.014	0.004	0.001	0.002	0.001	0.001	0.001
Voltage drop in ref. circuit	0.010	0.005	-0.001	0.001	-0.004	0.000	0.013	0.001	-0.018
# 15: HOT-SPRAYED ZINC									
Rebar Probe (volts)	-0.001	0.000	0.001	0.002	0.002	0.003	0.003	0.003	0.000
Reference Cell (volts)	0.301	0.296	0.307	0.295	0.280	0.285	0.274	0.264	0.290
Anode Voltage	49.6	49.8	49.7	49.9	49.7	49.1	50.1	50.2	49.6
Anode Current (amps)	0.17	1.00	0.20	0.07	0.01	0.02	0.01	0.01	0.01
Ref. Cell Instant-off (volts)	0.299	0.279	0.306	0.300	0.285	0.288	0.275	0.266	0.296
Conductance (mohs)	0.003	0.020	0.004	0.001	0.000	0.000	0.000	0.000	0.000
Voltage drop in ref. circuit	0.002	0.017	0.001	-0.005	-0.005	-0.003	-0.001	-0.002	-0.006

EVALUATION OF CATHODIC
BRIDGE PROTECTION SYSTEMS

APPENDIX A

Data spreadsheet

Date:	3/19/92	4/17/92
Days since last reading:	72	29
Days since start-up (10/5/88):	1,344	1,373
Tester:	DE	DE
# 11: HOT-SPRAYED ZINC		
Rebar Probe (volts)	0.001	0.002
Reference Cell (volts)	0.273	0.270
Anode Voltage	26.2	25.7
Anode Current (amps)	0.01	0.01
Ref. Cell Instant-off (volts)	0.273	0.264
Conductance (mohs)	0.000	0.000
Voltage drop in ref. circuit	0.000	0.006
# 12: HOT-SPRAYED ZINC		
Rebar Probe (volts)	0.001	0.001
Reference Cell (volts)	0.150	0.155
Anode Voltage	25.1	25.5
Anode Current (amps)	0.01	0.01
Ref. Cell Instant-off (volts)	0.145	0.147
Conductance (mohs)	0.000	0.000
Voltage drop in ref. circuit	0.005	0.008
# 13: HOT-SPRAYED ZINC		
Rebar Probe (volts)	-0.000	-0.001
Reference Cell (volts)	0.413	0.428
Anode Voltage	26.9	26.8
Anode Current (amps)	0.01	0.01
Ref. Cell Instant-off (volts)	0.434	0.442
Conductance (mohs)	0.000	0.000
Voltage drop in ref. circuit	-0.021	-0.014
# 14: HOT-SPRAYED ZINC		
Rebar Probe (volts)	0.001	0.002
Reference Cell (volts)	0.258	0.286
Anode Voltage	51.3	50.0
Anode Current (amps)	0.04	0.04
Ref. Cell Instant-off (volts)	0.252	0.281
Conductance (mohs)	0.001	0.001
Voltage drop in ref. circuit	0.006	0.005
# 15: HOT-SPRAYED ZINC		
Rebar Probe (volts)	0.001	0.001
Reference Cell (volts)	0.247	0.266
Anode Voltage	50.0	50.1
Anode Current (amps)	0.01	0.02
Ref. Cell Instant-off (volts)	0.244	0.262
Conductance (mohs)	0.000	0.000
Voltage drop in ref. circuit	0.003	0.004

EVALUATION OF CATHODIC
BRIDGE PROTECTION SYSTEMS

APPENDIX A

Data spreadsheet

Client: Texas Department of Transportation
Mr. Bill Burnett, Project Coordinator

Performed at: The College of Engineering,
Texas Tech University,
Lubbock, Texas

Faculty: Harry W. Parker, Ph.D, P.E.
Phil Nash, P.E.

Research Assistant: Robert W. Feingold

Date:	10/28/88	10/28/88	12/13/88	12/15/88	1/31/89	2/1/89	2/2/89	3/13/89	4/13/89
Days since last reading:	23	23	46	2	47	1	1	152	31
Days since start-up (10/5/88):	23	23	69	71	118	119	120	272	303
Tester:	Corrpro	Corrpro	Corrpro	Corrpro	Corrpro	Corrpro	Corrpro	MC,DR,DE	DR,DE,TD
# 16: HOT-SPRAYED ZINC									
Rebar Probe (volts)	-0.00123	0.00967	0.012	0.012	0.008	0.014	0.008	0.008	0.014
Reference Cell (volts)	0.380	1.050	0.825	0.605	0.508	0.434	0.518	0.489	0.717
Anode Voltage	-0.35	6.85	6.0	2.7	3.0	1.9	3.3	5.0	6.1
Anode Current (amps)	0.00	0.30	0.40	0.20	0.19	0.25	0.28	0.36	0.41
Ref. Cell Instant-off (volts)		0.450	0.627	0.479	0.440	0.365	0.444		
Conductance (mohs)		0.044	0.067	0.074	0.063	0.132	0.085	0.072	0.067
Voltage drop in ref. circuit		0.600	0.198	0.126	0.068	0.069	0.074		
11-16: AVERAGE VALUES: ZINC									
Rebar Probe (volts)	-0.009	0.015	0.012	0.017	0.007	0.008	0.006	0.007	0.010
Reference Cell (volts)	0.333	1.642	0.900	0.740	0.599	0.494	0.486	0.504	0.788
Anode Voltage	-0.3	7.8	6.4	3.1	8.2	5.6	9.7	12.2	9.4
Anode Current (amps)	0.00	0.47	0.54	0.29	0.27	0.32	0.34	0.37	0.43
Ref. Cell Instant-off (volts)		0.595	0.724	0.592	0.485	0.403	0.415		
Conductance (mohs)		0.057	0.145	0.117	0.059	0.154	0.126	0.056	0.085
Voltage drop in ref. circuit		1.046	0.270	0.224	0.114	0.091	0.071		
# 17: CONDUCTIVE PAINT									
Rebar Probe (volts)	-0.00509	0.00851	0.013	0.011	0.011	0.013	0.009	0.007	0.009
Reference Cell (volts)	0.253	1.160	*OOS*	1.945	1.929	1.335	1.209	1.040	1.735
Anode Voltage	0.026	7.06	9.9	7.3	7.9	5.5	7.0	9.500	7.8
Anode Current (amps)	0.00	2.25	2.39	1.52	1.49	1.29	1.31	1.360	1.38
Ref. Cell Instant-off (volts)		0.400	0.956	0.691	0.795	0.690	0.740		
Conductance (mohs)		0.319	0.241	0.208	0.189	0.235	0.187	0.143	0.177
Voltage drop in ref. circuit		0.760		1.254	1.134	0.645	0.469		
Total Current (amps)	0.00	54.00	56.75	49.90	48.90	50.20	50.70	51.80	52.40
Check: sum of anode currents		53.45	56.17	49.87	49.20	50.50	50.96	52.05	52.57
% Difference		1.03%	1.03%	0.06%	-0.61%	-0.59%	-0.51%	-0.48%	-0.32%
Comments	Rectifier "OFF" "pre-energization data".	Initial energization data.	Before depolarization testing. *OOS* = "out of scale"	Re-energization data.	Before depolarization testing.	Re-energization data.			

EVALUATION OF CATHODIC
BRIDGE PROTECTION SYSTEMS

APPENDIX A

Data spreadsheet

Key to tester names:
MC - Mike Chetty
DR - Dan Richardson
DE - David Elmore
TD - Todd Darden
JM - John Moore
KC - Ken Corse

Date:	5/26/89	6/13/89	7/17/89	8/18/89	9/19/89	10/31/89	11/28/89	1/9/90	1/17/90
Days since last reading:	43	18	34	32	32	42	28	12	8
Days since start-up (10/5/88):	346	364	398	430	462	504	532	544	552
Tester:	DR	JM,DR	DR,KC	DR	DR	DR	DR	DR,DE	DR
# 16: HOT-SPRAYED ZINC									
Rebar Probe (volts)	0.002	-0.000	0.003	0.002	0.001	-0.001	-0.001	-0.001	-0.001
Reference Cell (volts)	0.276	0.262	0.289	0.333	0.373	0.385	0.395	0.414	0.405
Anode Voltage	19.8	21.2	49.0	49.1	49.5	49.9	53.5	50.8	49.5
Anode Current (amps)	0.38	0.43	0.22	0.18	0.08	0.17	0.86	0.15	0.15
Ref. Cell Instant-off (volts)								0.405	
Conductance (mohs)	0.019	0.020	0.004	0.004	0.002	0.003	0.016	0.003	0.003
Voltage drop in ref. circuit								0.009	
11-16: AVERAGE VALUES: ZINC									
Rebar Probe (volts)	0.001	0.002	0.004	0.003	0.001	0.001	0.000	0.000	0.001
Reference Cell (volts)	0.382	0.493	0.457	0.427	0.452	0.347	0.311	0.367	0.430
Anode Voltage	28.5	26.6	31.1	32.6	37.5	38.1	40.6	38.8	38.2
Anode Current (amps)	0.26	0.33	0.14	0.11	0.10	0.16	0.35	0.12	0.10
Ref. Cell Instant-off (volts)								0.370	
Conductance (mohs)	0.010	0.013	0.005	0.004	0.002	0.004	0.008	0.003	0.002
Voltage drop in ref. circuit								-0.003	
# 17: CONDUCTIVE PAINT									
Rebar Probe (volts)	0.010	0.004	0.008	0.008	0.005	0.003	0.001	0.003	0.005
Reference Cell (volts)	1.008	0.789	0.806	1.064	1.054	0.758	0.302	0.701	1.492
Anode Voltage	46.5	9.8	33.5	27.2	26.8	49.6	60.6	51.5	22.1
Anode Current (amps)	1.28	1.35	1.24	1.27	1.28	1.28	0.20	1.00	1.25
Ref. Cell Instant-off (volts)								0.408	
Conductance (mohs)	0.028	0.138	0.037	0.047	0.048	0.026	0.003	0.019	0.057
Voltage drop in ref. circuit								0.293	
Total Current (amps)	50.30	51.20	48.70	48.80	48.80	49.10	49.00	49.30	49.40
Check: sum of anode currents	50.52	51.37	49.13	49.07	49.34	49.91	51.25	50.06	49.79
% Difference	-0.44%	-0.33%	-0.88%	-0.55%	-1.09%	-1.62%	-4.39%	-1.52%	-0.78%
Comments				Overcoat on zinc anode is deterior-ating. It is in poor condition.				Overcoat on zinc anode continues to deterior-ate. It is in "very poor condition."	Made after rate of corrosion test was performed.

EVALUATION OF CATHODIC
BRIDGE PROTECTION SYSTEMS

APPENDIX A

Data spreadsheet

This spreadsheet is a compilation of the voltage and current data gathered at monthly intervals from the various cathodic protection circuits on the bridge (the Highway 87 overpass, in Big Spring, Texas).

Date:	4/26/90	11/19/90	3/28/91	5/15/91	7/31/91	8/16/91	9/10/91	10/9/91	1/7/92
Days since last reading:	99	207	129	48	77	16	25	29	90
Days since start-up (10/5/88):	651	858	987	1,035	1,112	1,128	1,153	1,182	1,272
Tester:	DE,TD	JM,DE	DE,KC	DE	DE	JM,DE	DE	DE	DE
# 16: HOT-SPRAYED ZINC									
Rebar Probe (volts)	-0.001	-0.001	0.000	0.002	0.000	0.002	0.001	0.001	-0.001
Reference Cell (volts)	0.407	0.400	0.400	0.367	0.381	0.403	0.381	0.406	0.425
Anode Voltage	48.5	49.8	50.9	50.5	49.3	49.2	50.3	50.7	49.9
Anode Current (amps)	0.10	1.96	0.55	0.05	0.02	0.03	0.02	0.02	0.02
Ref. Cell Instant-off (volts)	0.411	0.398	0.398	0.267	0.390	0.409	0.383	0.407	0.418
Conductance (mohs)	0.002	0.039	0.011	0.001	0.000	0.001	0.000	0.000	0.000
Voltage drop in ref. circuit	-0.004	0.002	0.002	0.100	-0.009	-0.006	-0.002	-0.001	0.007
11-16: AVERAGE VALUES: ZINC									
Rebar Probe (volts)	0.000	0.000	0.001	0.003	0.002	0.003	0.002	0.002	0.000
Reference Cell (volts)	0.336	0.335	0.344	0.309	0.320	0.302	0.318	0.306	0.351
Anode Voltage	37.5	37.7	34.1	38.0	37.5	37.2	38.0	38.1	37.7
Anode Current (amps)	0.15	1.38	0.26	0.07	0.02	0.03	0.02	0.02	0.02
Ref. Cell Instant-off (volts)	0.336	0.317	0.343	0.294	0.325	0.305	0.317	0.296	0.337
Conductance (mohs)	0.004	0.040	0.005	0.002	0.001	0.001	0.000	0.000	0.001
Voltage drop in ref. circuit	0.001	0.018	0.002	0.014	-0.005	-0.003	0.002	0.011	0.013
# 17: CONDUCTIVE PAINT									
Rebar Probe (volts)	0.002	0.004	0.002	0.004	0.003	0.006	0.005	0.003	0.001
Reference Cell (volts)	0.647	1.192	0.394	0.581	0.684	0.775	0.770	0.668	0.578
Anode Voltage	7.8	27.6	53.2	23.3	20.0	17.3	40.3	50.0	15.2
Anode Current (amps)	1.35	2.66	1.50	1.28	1.29	1.28	1.27	0.85	1.32
Ref. Cell Instant-off (volts)	0.437	0.509	0.308	0.367	0.407	0.427	0.423	0.381	0.398
Conductance (mohs)	0.173	0.096	0.028	0.055	0.065	0.074	0.032	0.017	0.087
Voltage drop in ref. circuit	0.210	0.683	0.086	0.214	0.277	0.348	0.347	0.287	0.180
Total Current (amps)	49.40	47.60	43.90	36.20	28.80	28.40	28.10	27.60	28.40
Check: sum of anode currents	49.10	56.92	46.42	36.56	28.98	28.65	28.30	27.76	28.55
% Difference	0.61%	-16.37%	-5.43%	-0.98%	-0.62%	-0.87%	-0.71%	-0.58%	-0.53%
Comments		*ns* = "not stable"	Circuits # 11 - 17: Erratic readings of anode current: moving switch varies reading.						

EVALUATION OF CATHODIC
BRIDGE PROTECTION SYSTEMS

APPENDIX A

Data spreadsheet

Date:	3/19/92	4/17/92
Days since last reading:	72	29
Days since start-up (10/5/88):	1,344	1,373
Tester:	DE	DE
# 16: HOT-SPRAYED ZINC		
Rebar Probe (volts)	-0.001	-0.000
Reference Cell (volts)	0.400	0.409
Anode Voltage	51.1	50.4
Anode Current (amps)	0.02	0.02
Ref. Cell Instant-off (volts)	0.405	0.402
Conductance (mohs)	0.000	0.000
Voltage drop in ref. circuit	-0.005	0.007
11-16: AVERAGE VALUES: ZINC		
Rebar Probe (volts)	0.000	0.001
Reference Cell (volts)	0.290	0.302
Anode Voltage	38.4	38.1
Anode Current (amps)	0.02	0.02
Ref. Cell Instant-off (volts)	0.292	0.300
Conductance (mohs)	0.000	0.000
Voltage drop in ref. circuit	-0.002	0.003
# 17: CONDUCTIVE PAINT		
Rebar Probe (volts)	0.001	0.003
Reference Cell (volts)	0.424	0.472
Anode Voltage	50.2	29.4
Anode Current (amps)	0.74	1.31
Ref. Cell Instant-off (volts)	0.344	0.366
Conductance (mohs)	0.015	0.045
Voltage drop in ref. circuit	0.080	0.106
Total Current (amps)	28.10	28.40
Check: sum of anode currents	28.21	28.51
% Difference	-0.39%	-0.39%
Comments		"Texas Tech members present"

APPENDIX B

DATA TIME HISTORIES

FIGURE B-1
ANODE CURRENT - ELGARD 150 MESH

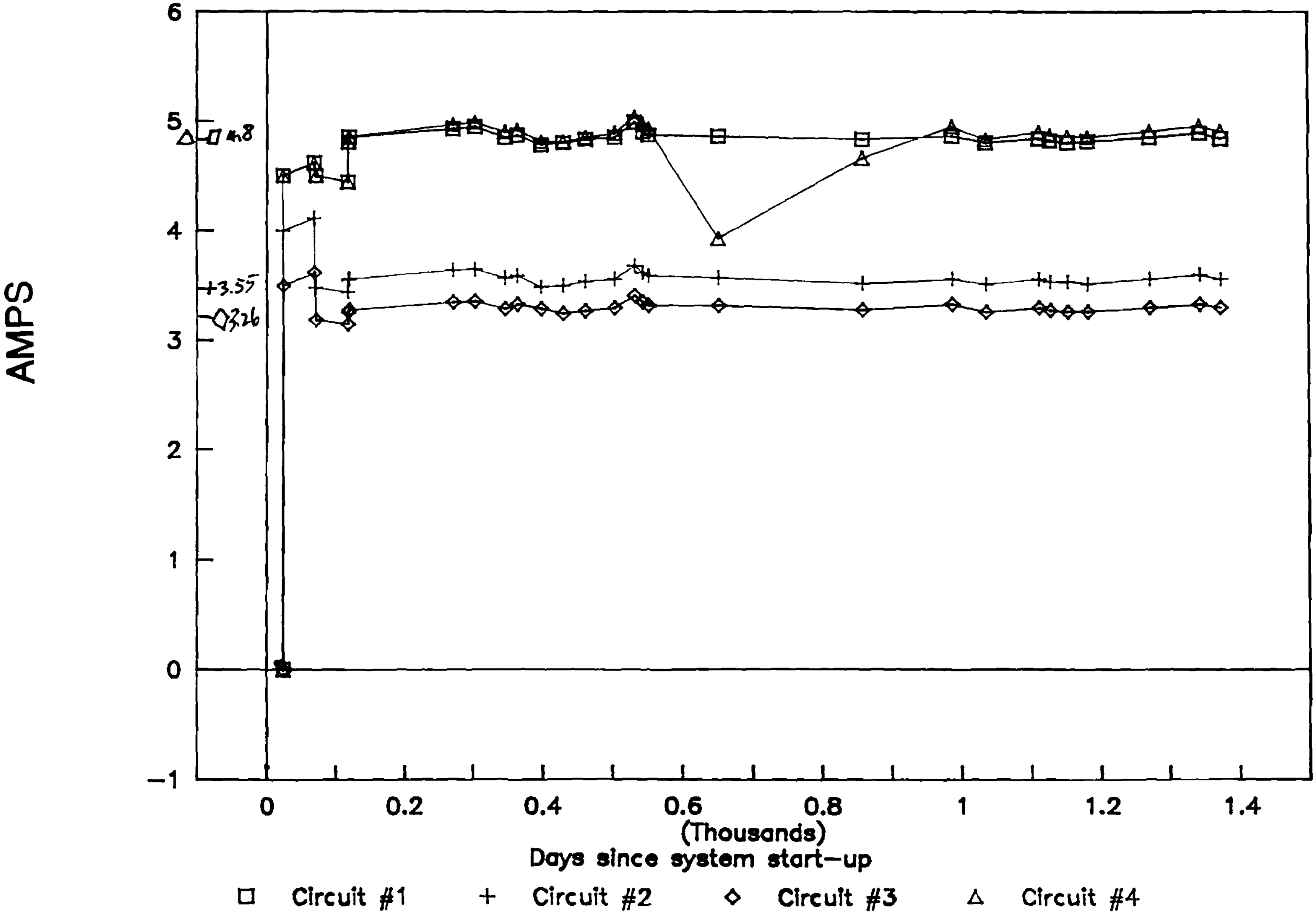


FIGURE B-2
ANODE VOLTAGE - ELGARD 150 MESH

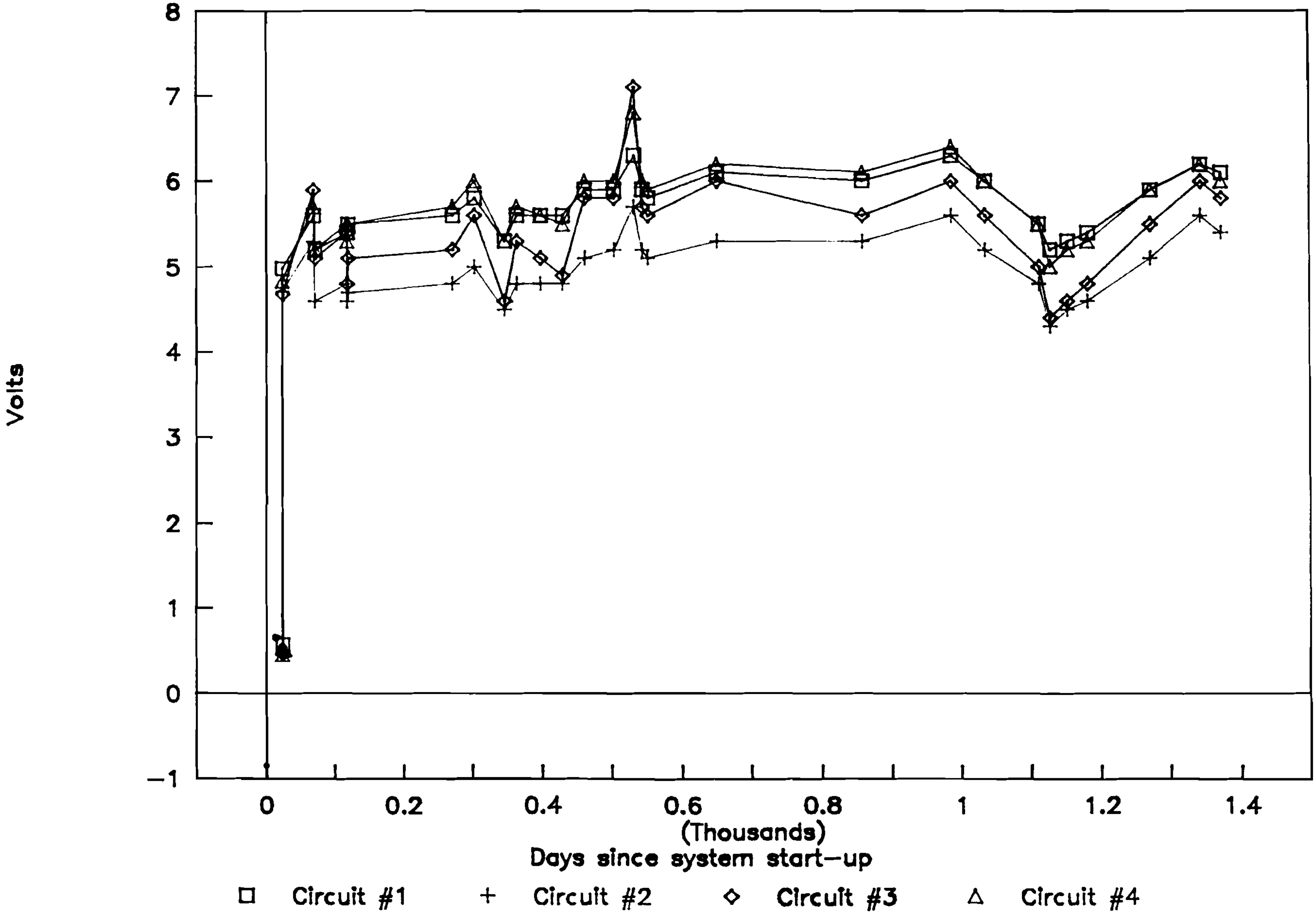


FIGURE B-3
REBAR PROBE VOLTAGE - ELGARD 150 MESH

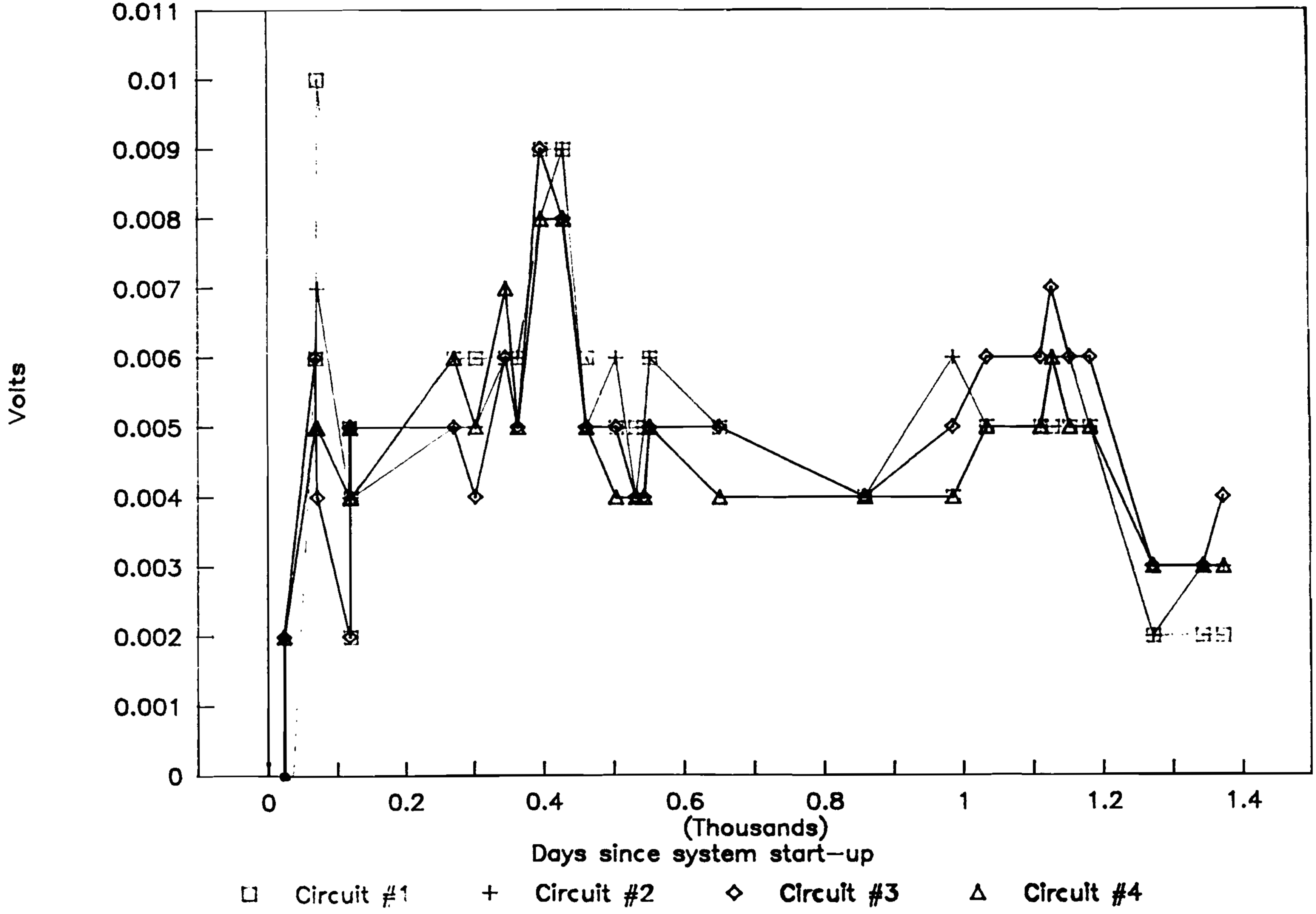


FIGURE B-4
INSTANT-OFF VOLTAGE - ELGARD 150 MESH

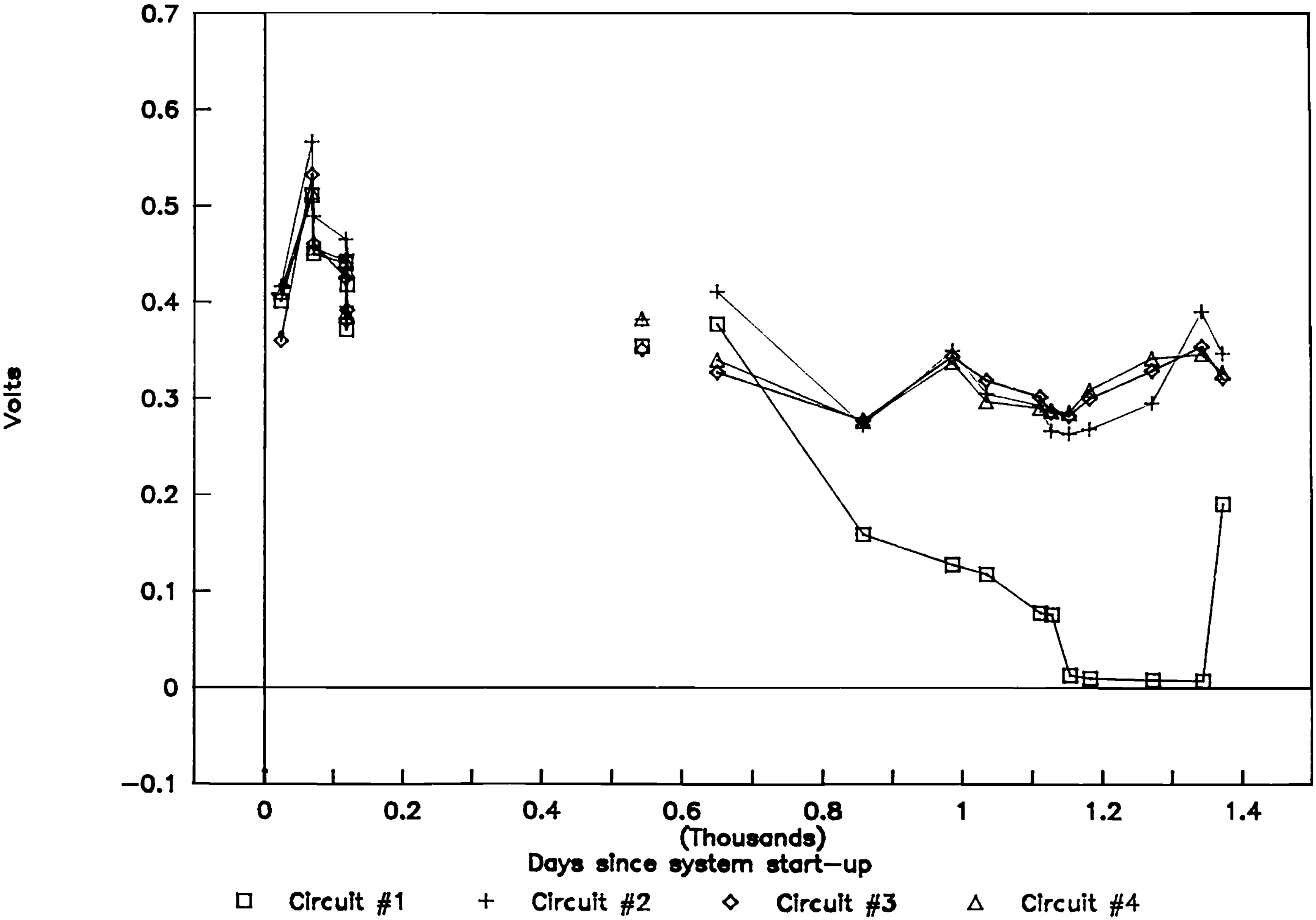


FIGURE B-5
REFERENCE CELL VOLTAGE - ELGARD 150 MESH

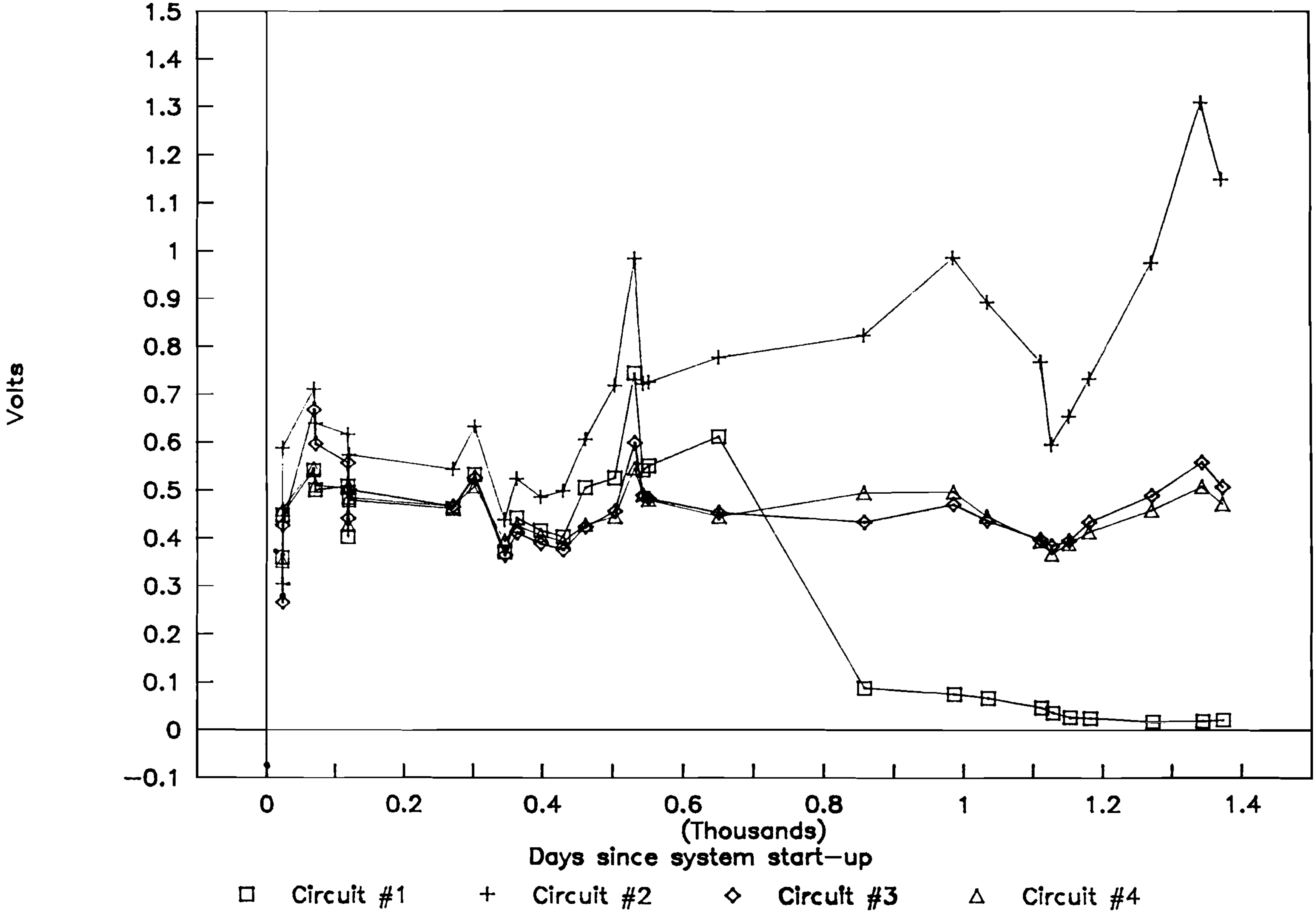


FIGURE B-6
ANODE CURRENT - RAYCHEM FEREX 100

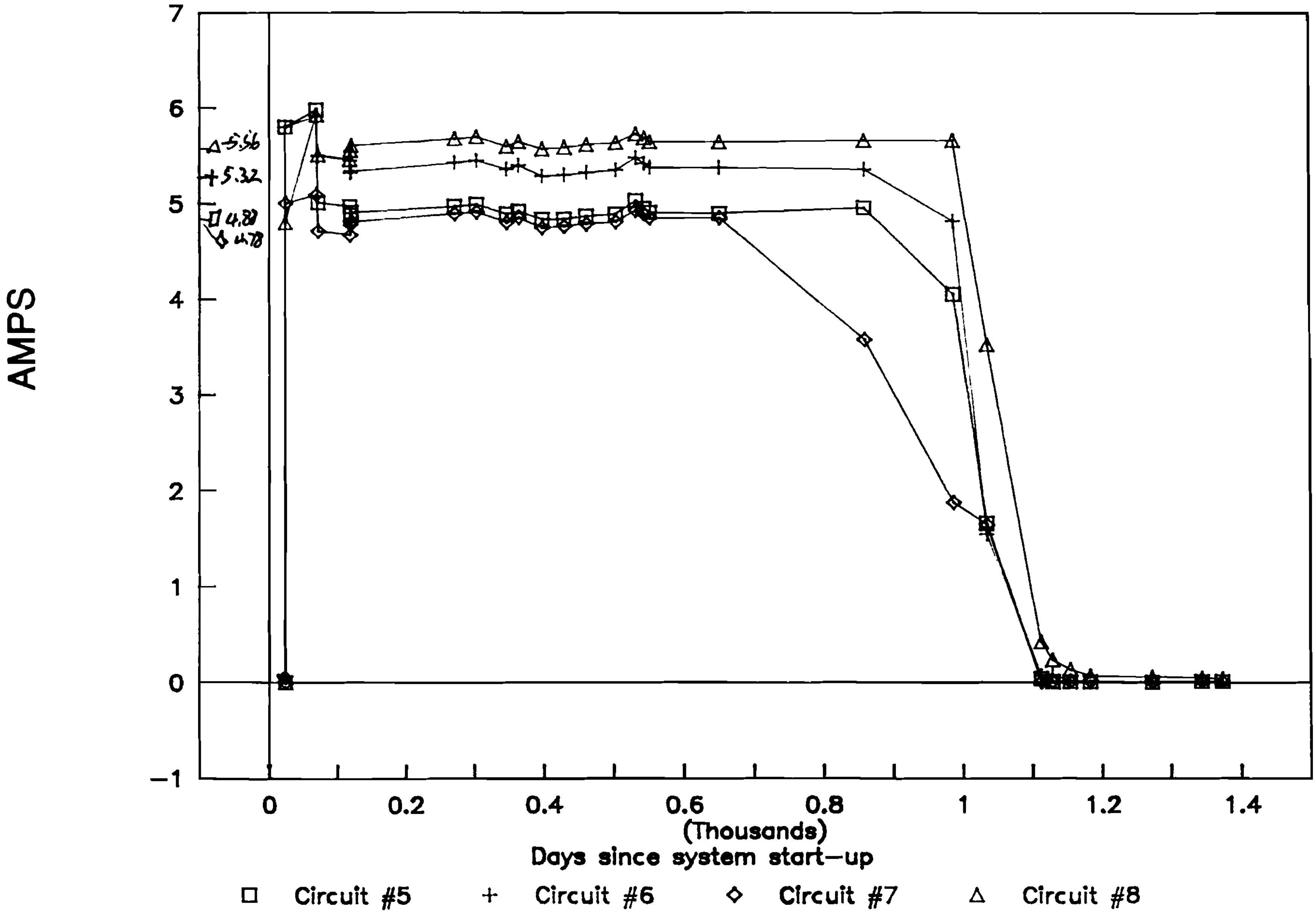


FIGURE B-7
ANODE VOLTAGE - RAYCHEM FEREX 100

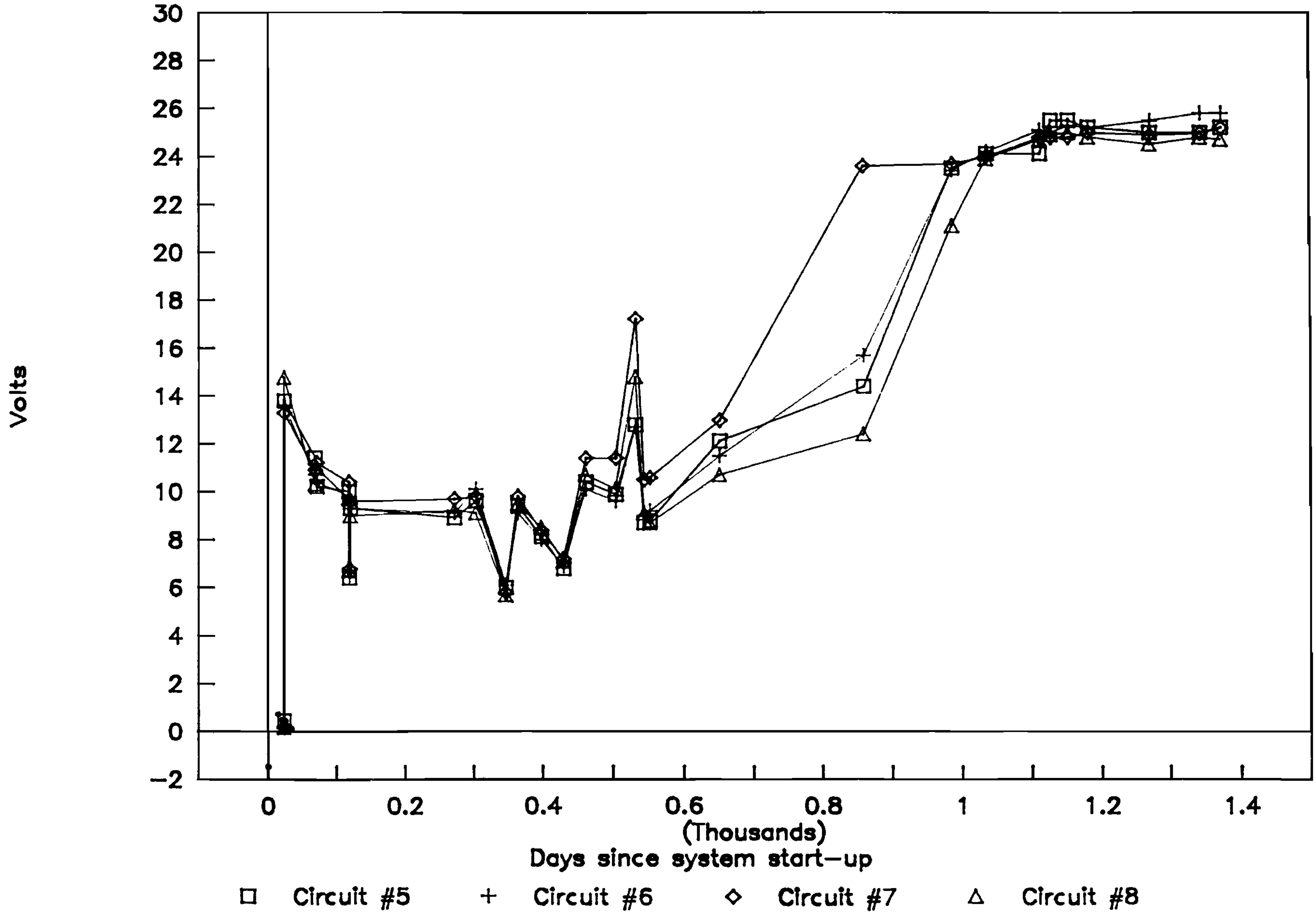


FIGURE B-8
REBAR PROBE VOLTAGE - RAYCHEM FEREX 100

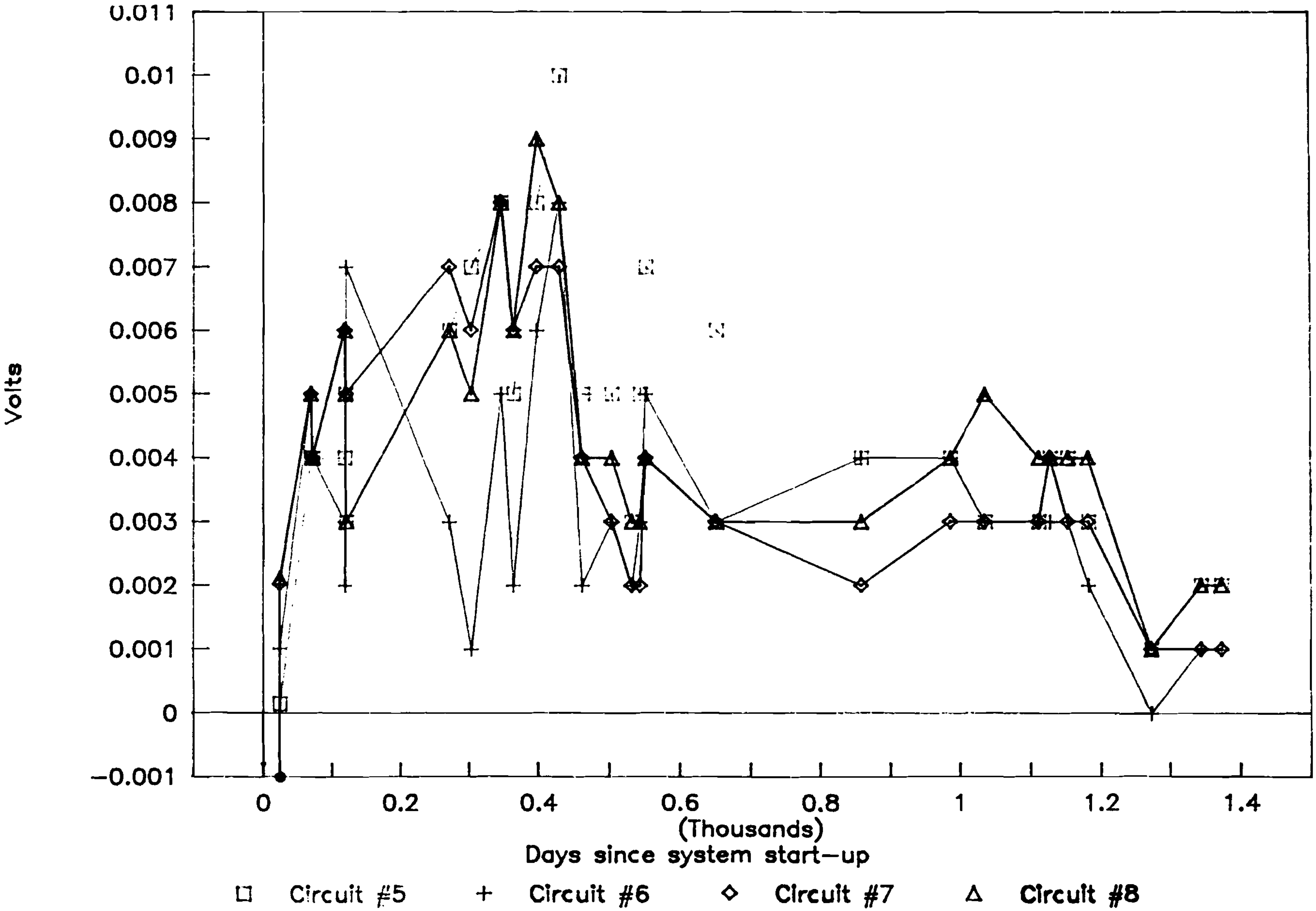


FIGURE B-9
INSTANT-OFF VOLTAGE - RAYCHEM FEREX 100

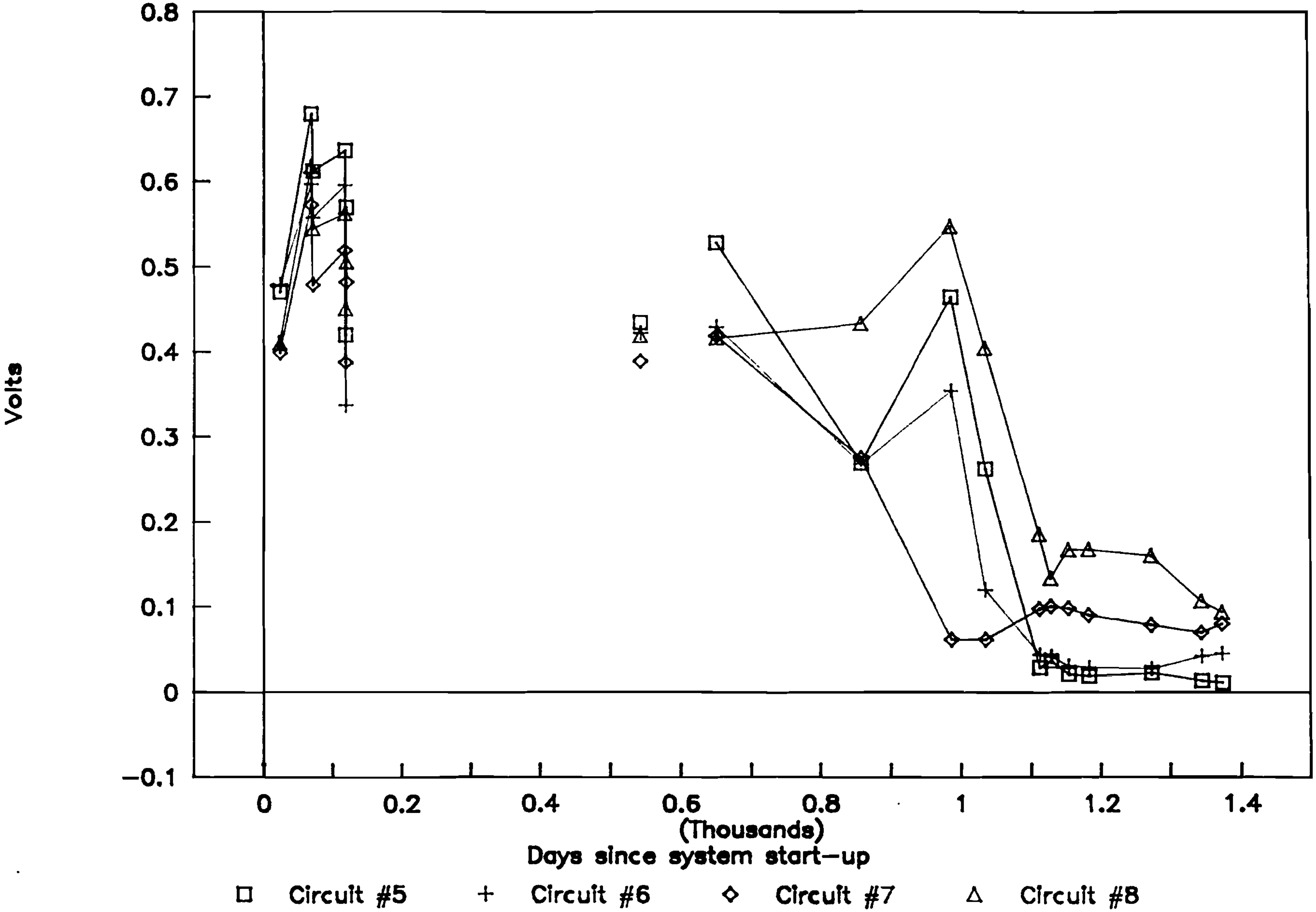


FIGURE B-10
REFERENCE CELL VOLTAGE - RAYCHEM FEREX 100

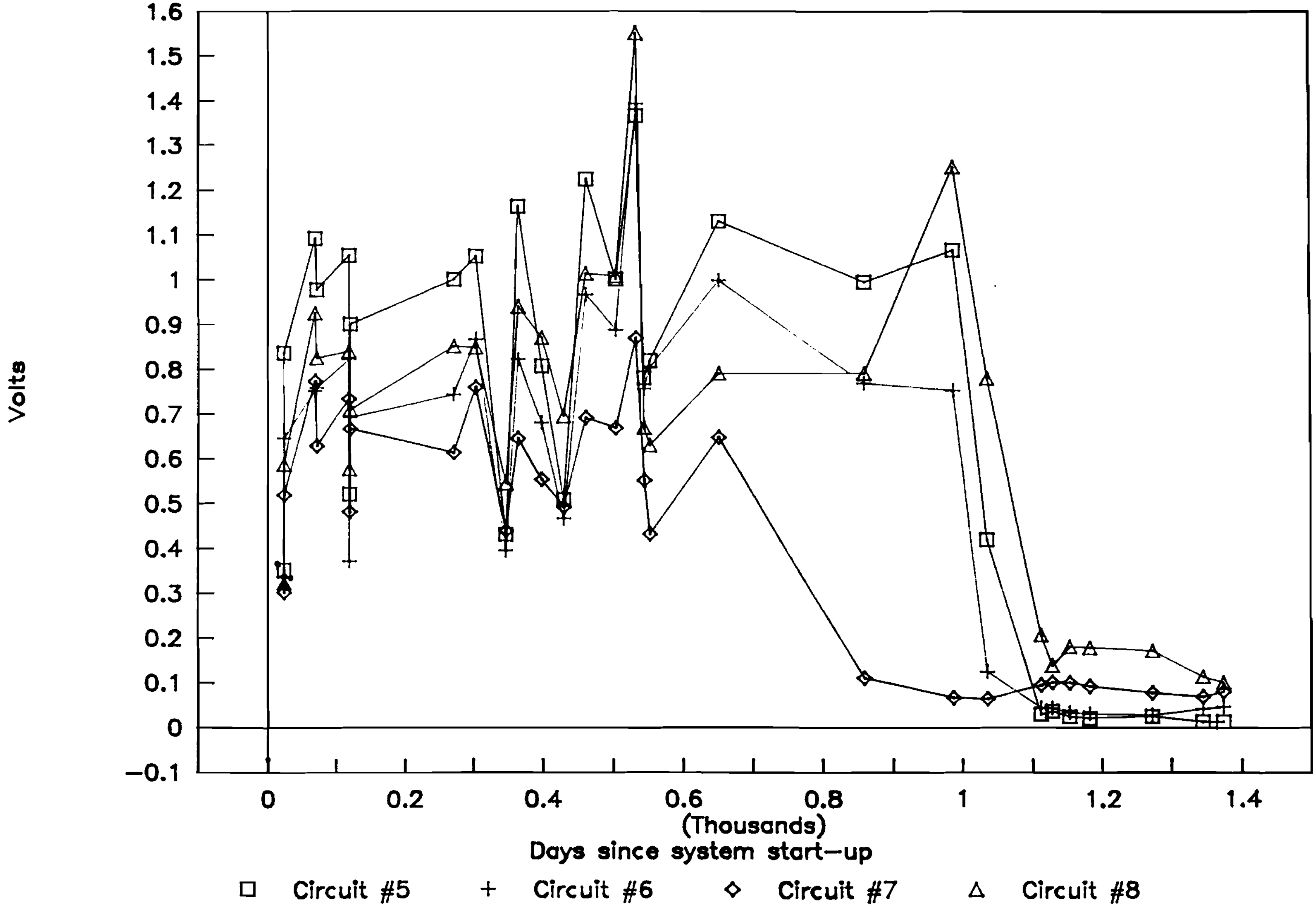


FIGURE B-11
APPARENT CONDUCTANCE - RAYCHEM FEREX 100

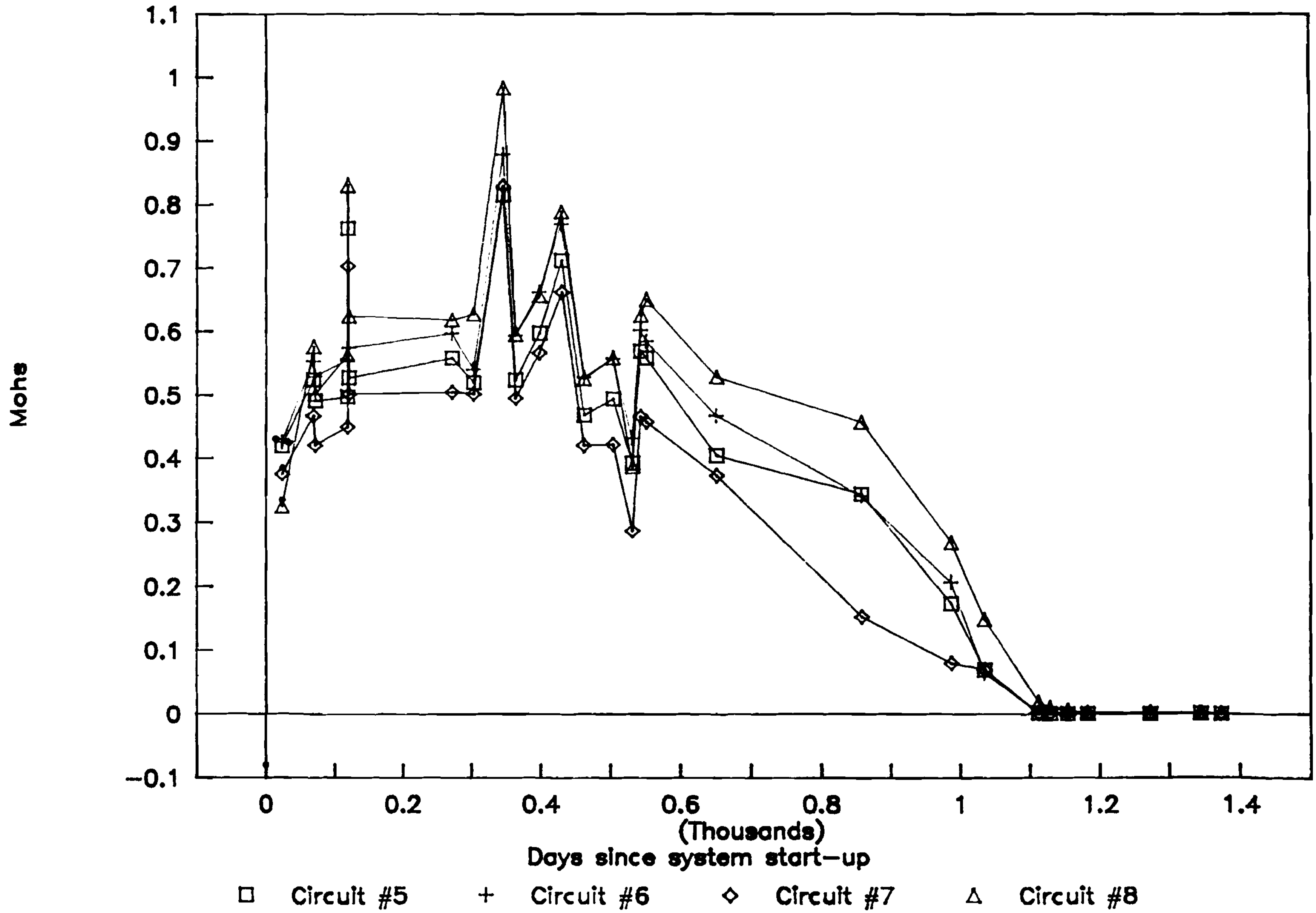


FIGURE B-12
ANODE CURRENT - RESCON POLYMER CONCRETE

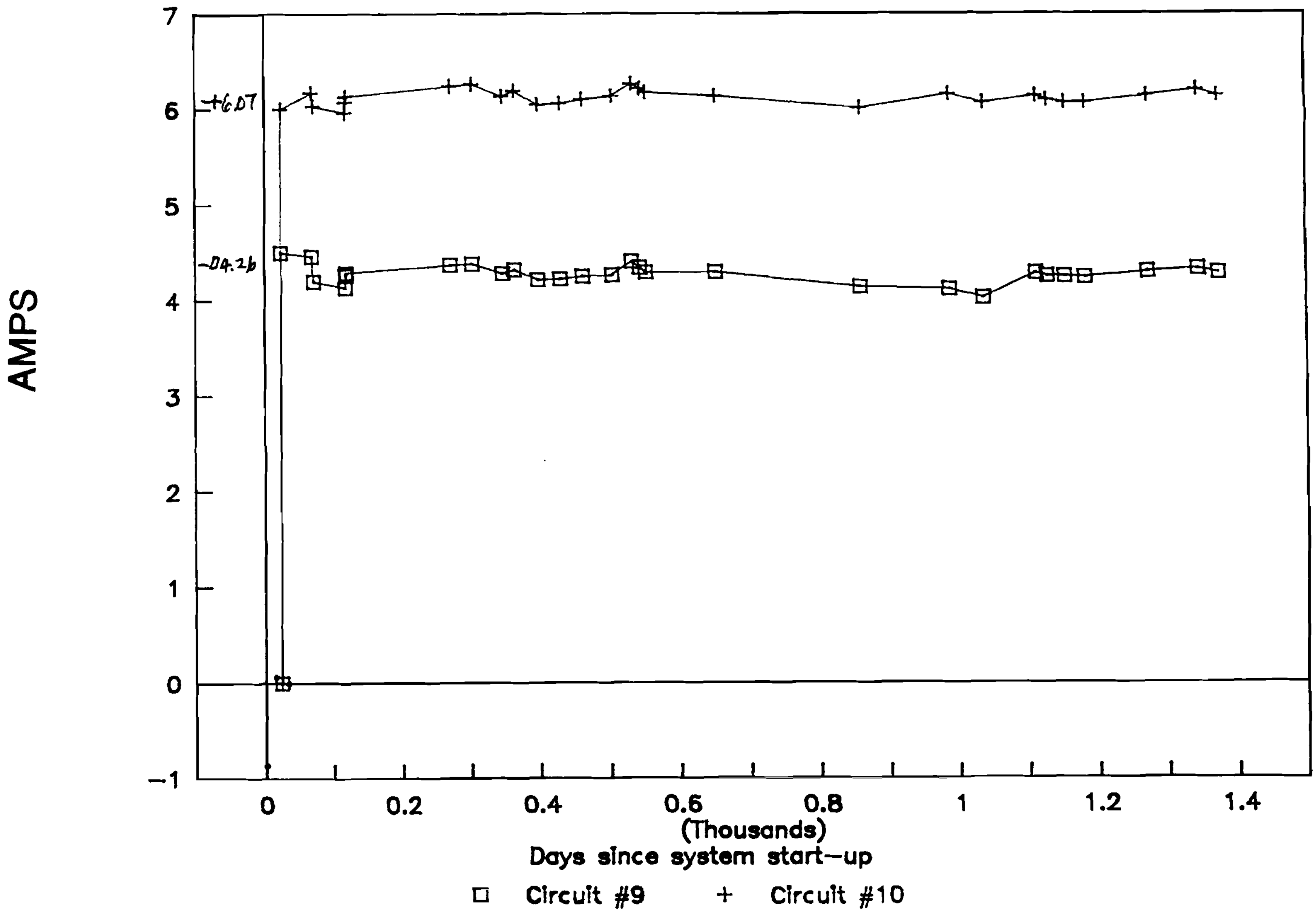


FIGURE B-13
ANODE VOLTAGE - RESCON POLYMER CONCRETE

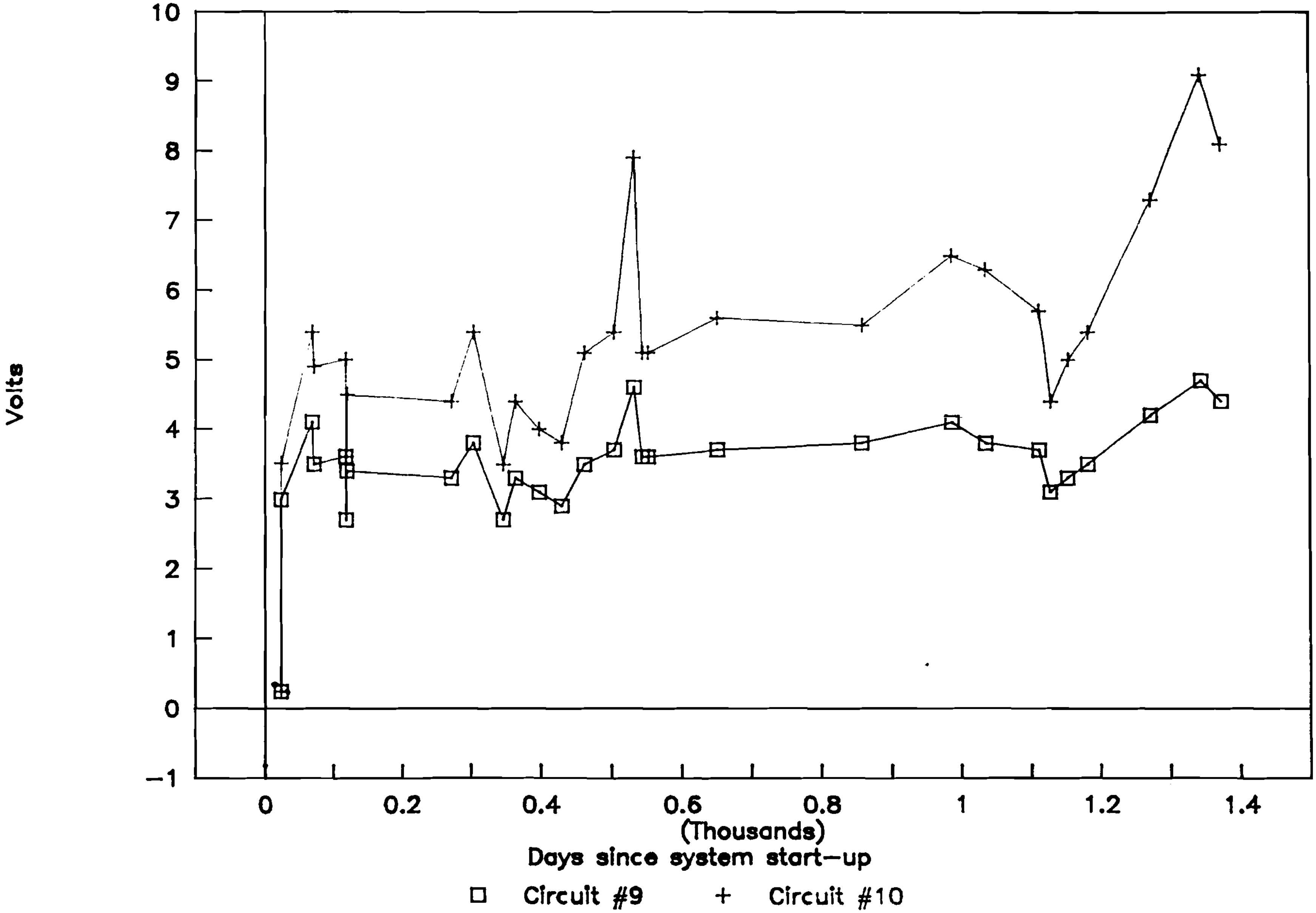


FIGURE B-14
REBAR PROBE VOLTAGE - RESCON POLYMER CONCRETE

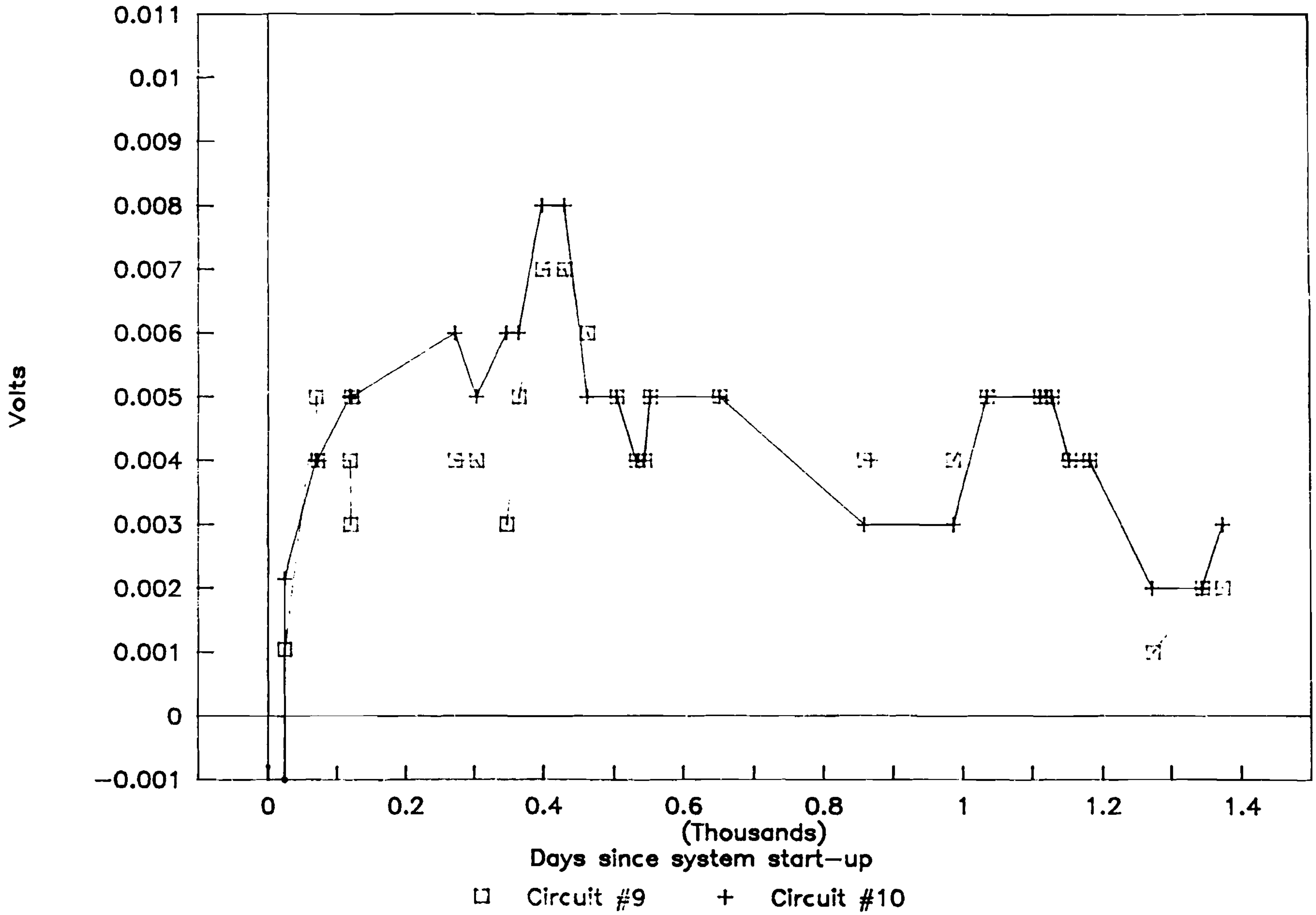


FIGURE B-15
INSTANT-OFF VOLTAGE - RESCON POLYMER CONCRETE

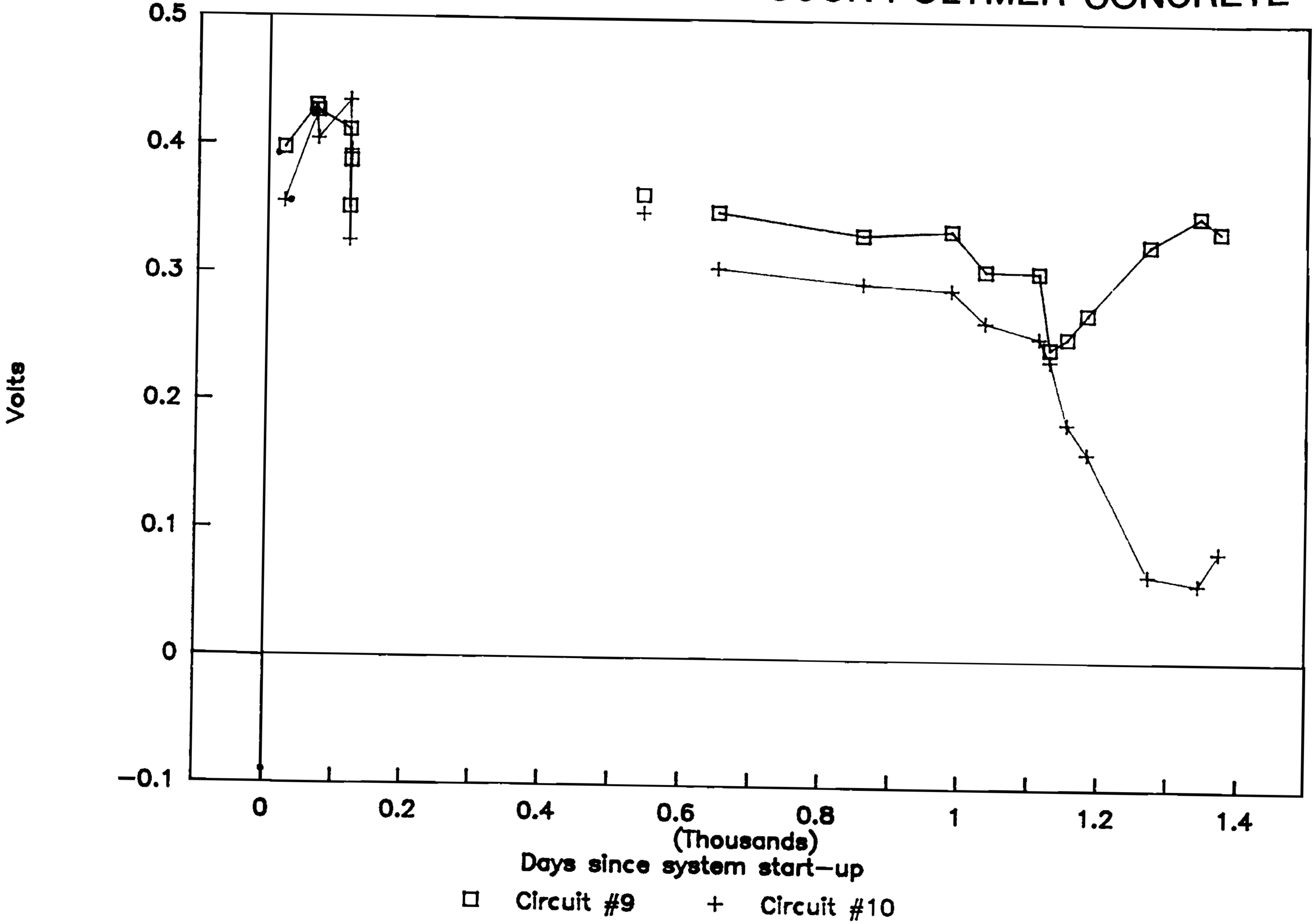


FIGURE B-16
REFERENCE CELL VOLTAGE - RESCON POLYMER CONCRETE

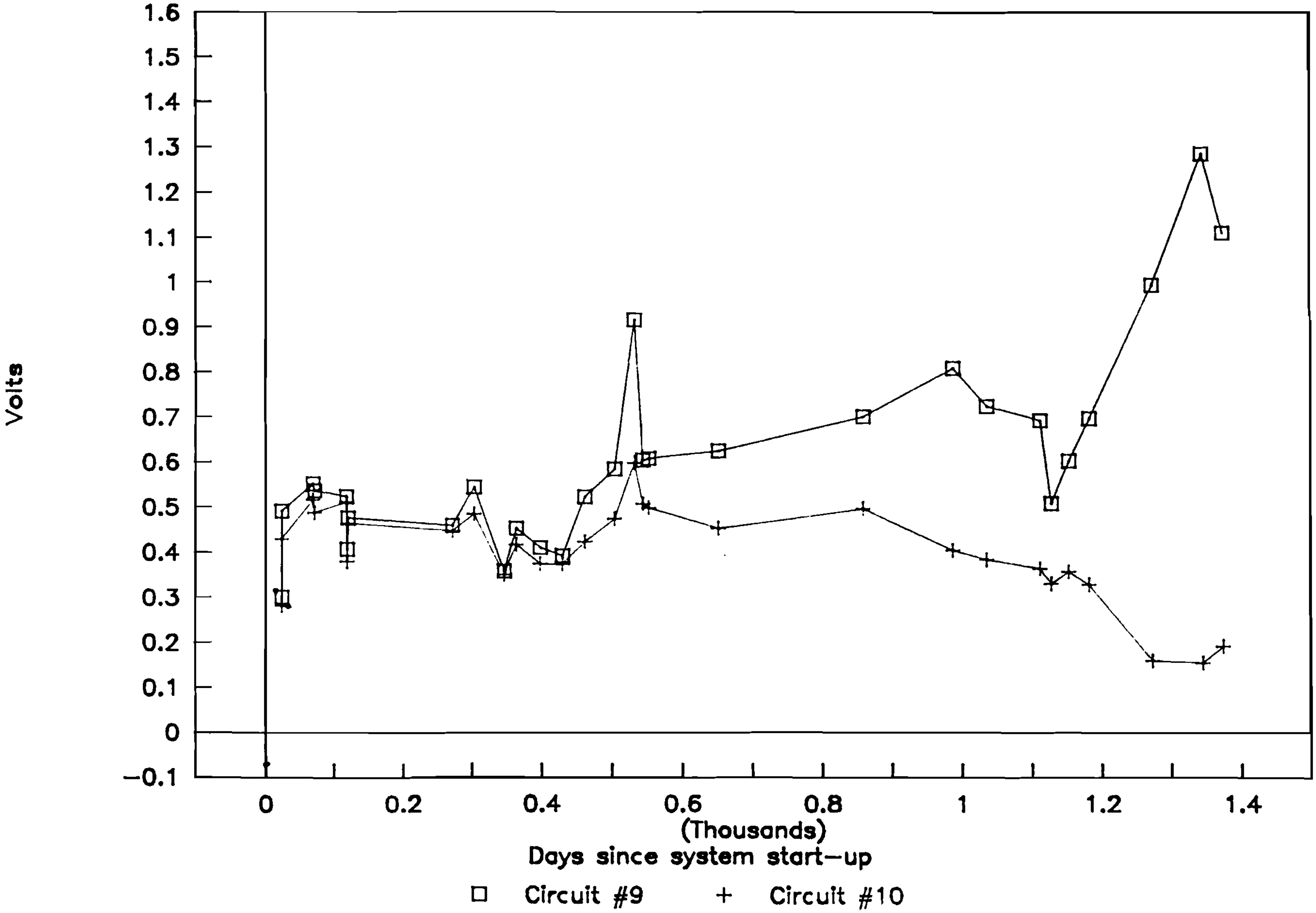


FIGURE B-17
ANODE CURRENT - SPRAYED ZINC (CIRCUITS 11-13)

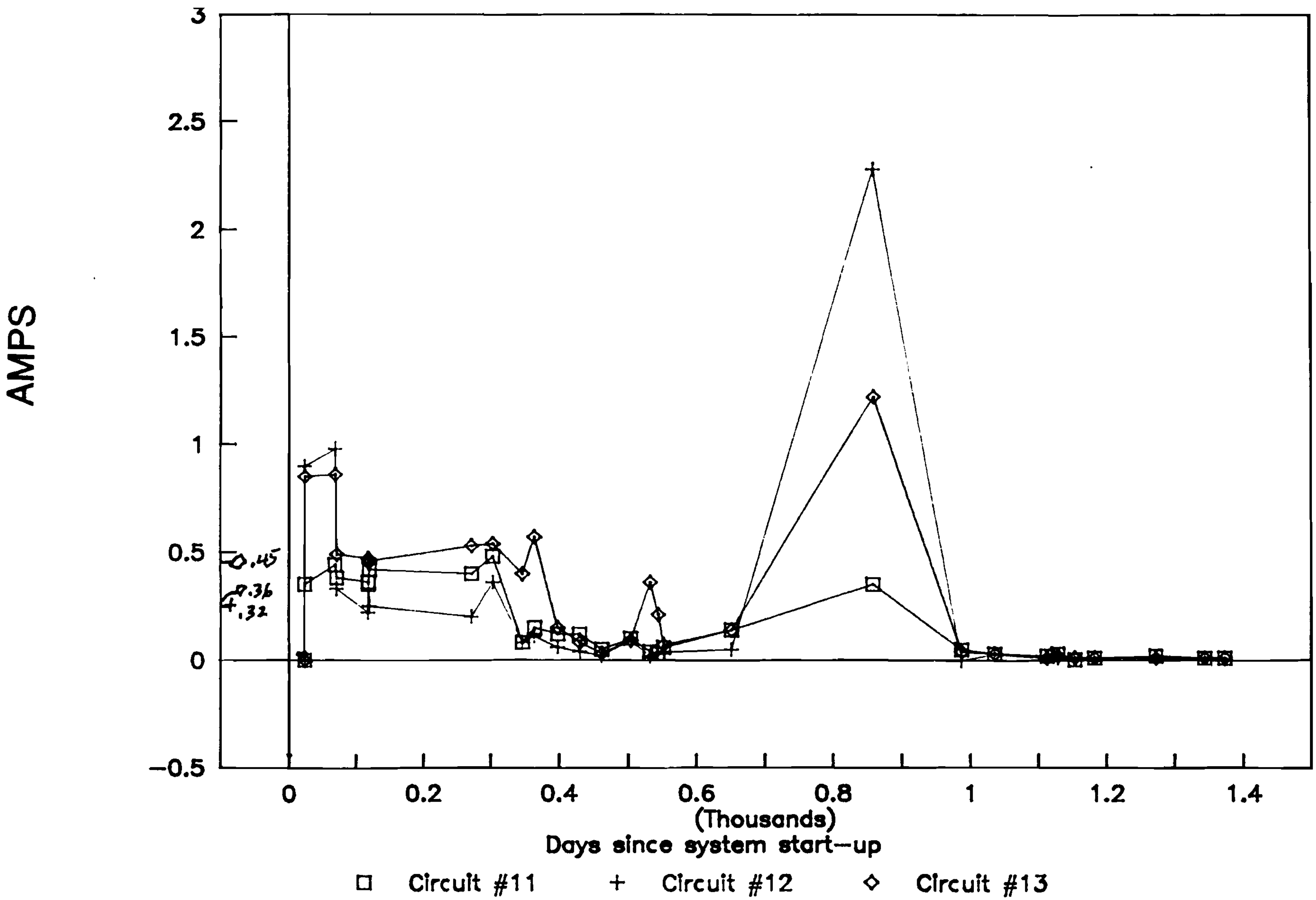


FIGURE B-18
ANODE VOLTAGE - SPRAYED ZINC (CIRCUITS 11-13)

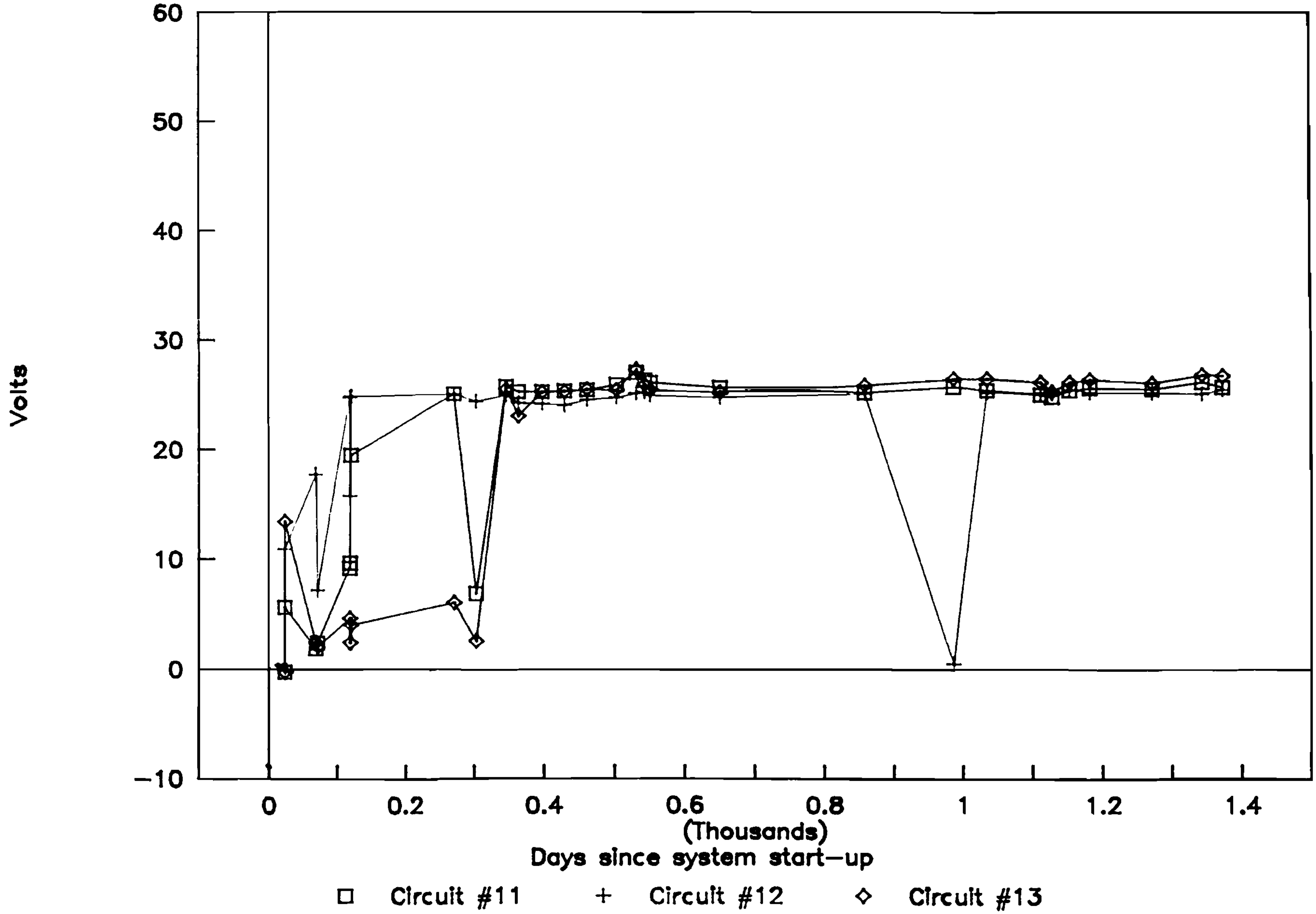


FIGURE B-19
REBAR PROBE VOLTAGE - SPRAYED ZINC (CIRCUITS 11-13)

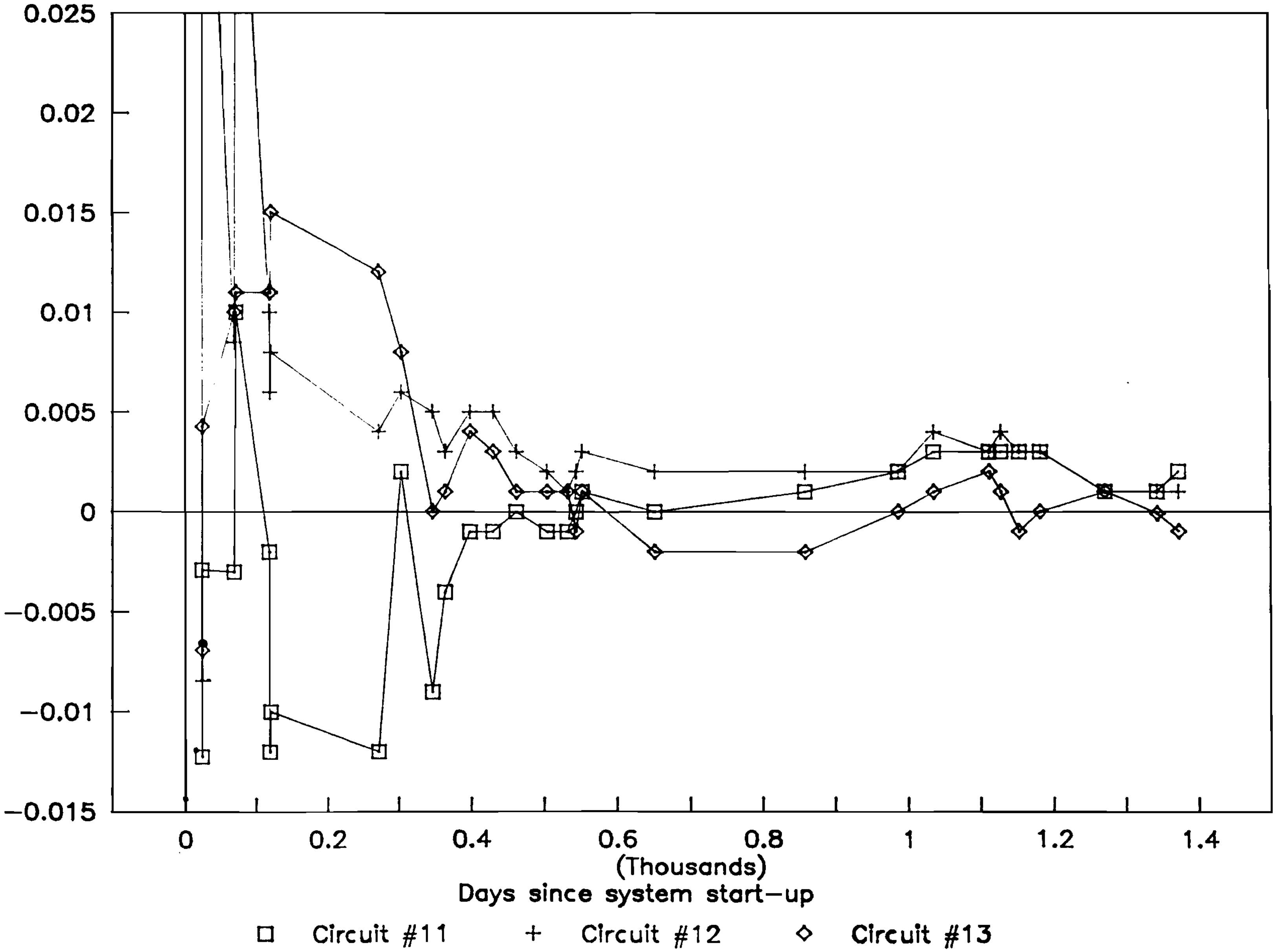


FIGURE B-20
INSTANT-OFF VOLTAGE - SPRAYED ZINC (CIRCUITS 11-13)

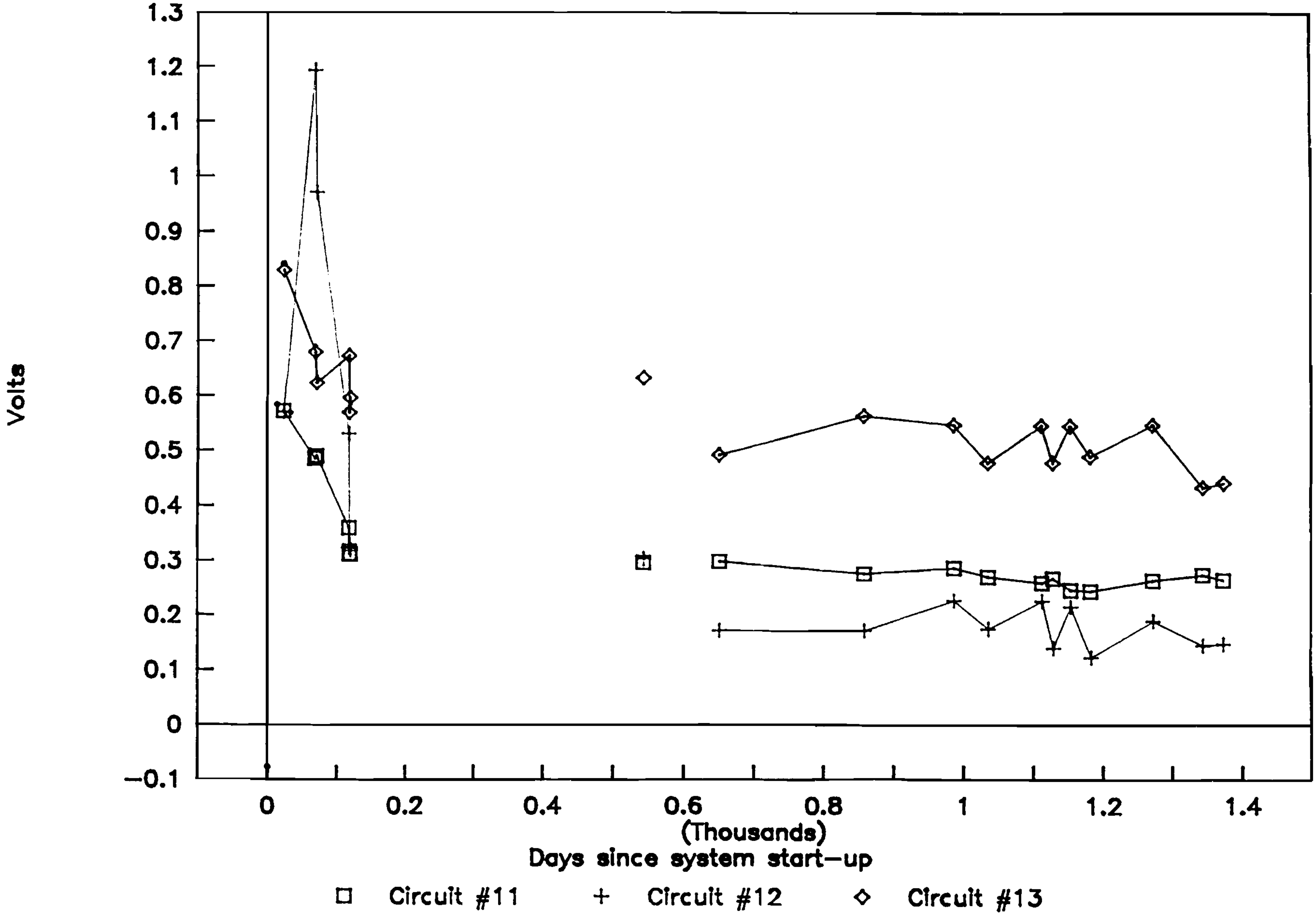
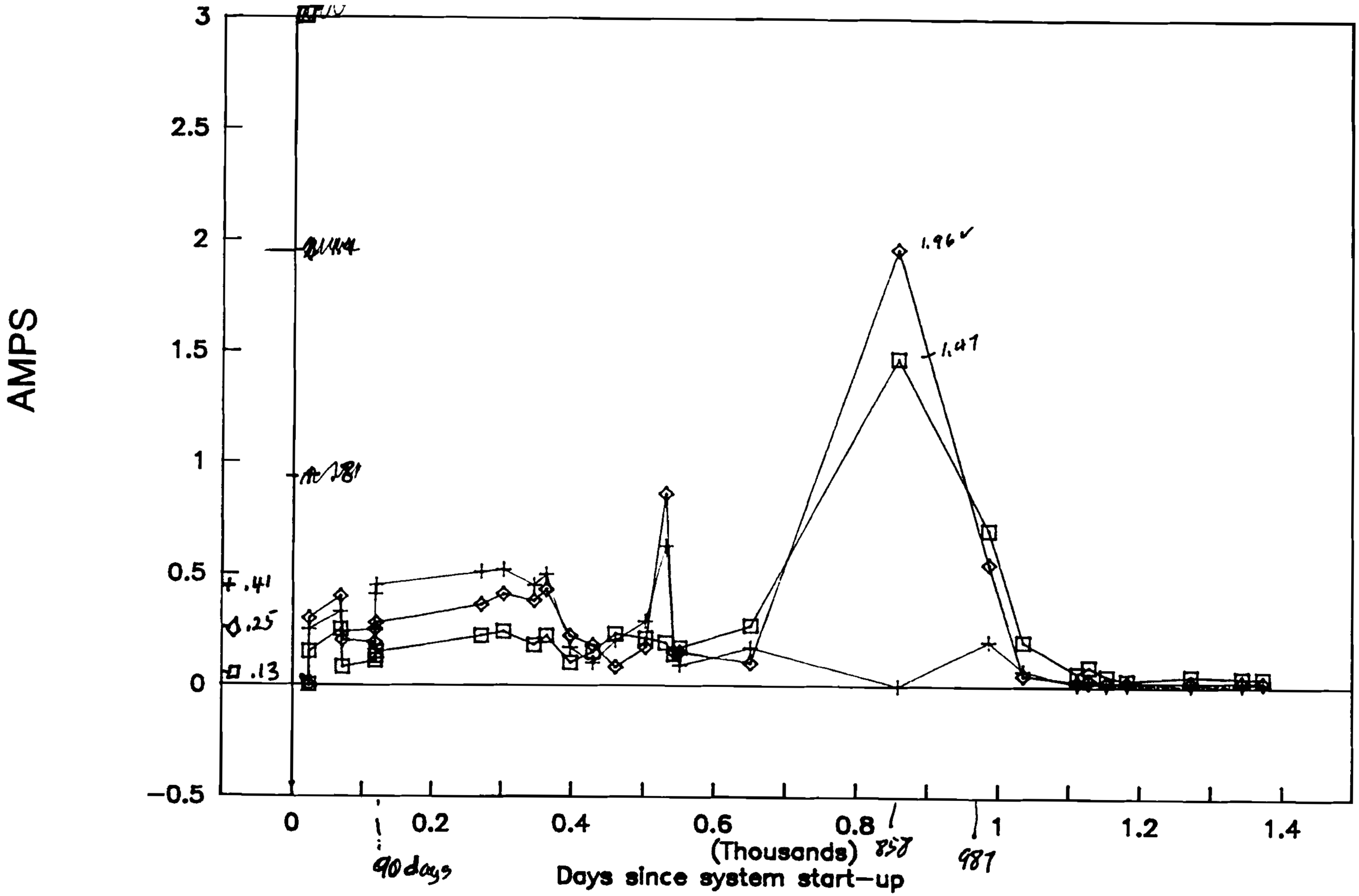


FIGURE B-21
ANODE CURRENT - SPRAYED ZINC (CIRCUITS 14-16)



□ Circuit #14 + Circuit #15 ◇ Circuit #16

FIGURE B-22
ANODE VOLTAGE - SPRAYED ZINC (CIRCUITS 14-16)

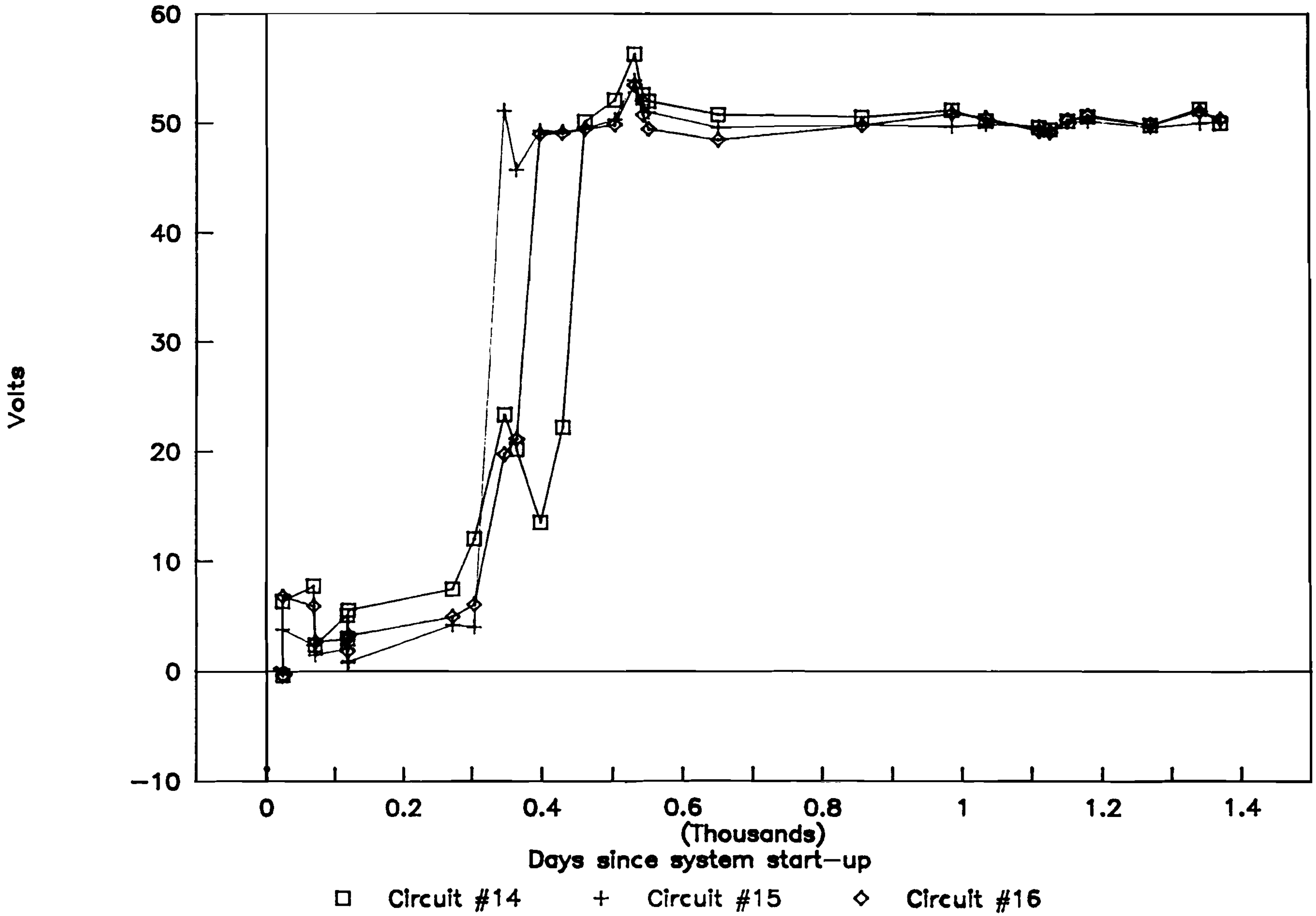


FIGURE B-23
REBAR PROBE VOLTAGE - SPRAYED ZINC (CIRCUITS 14-16)

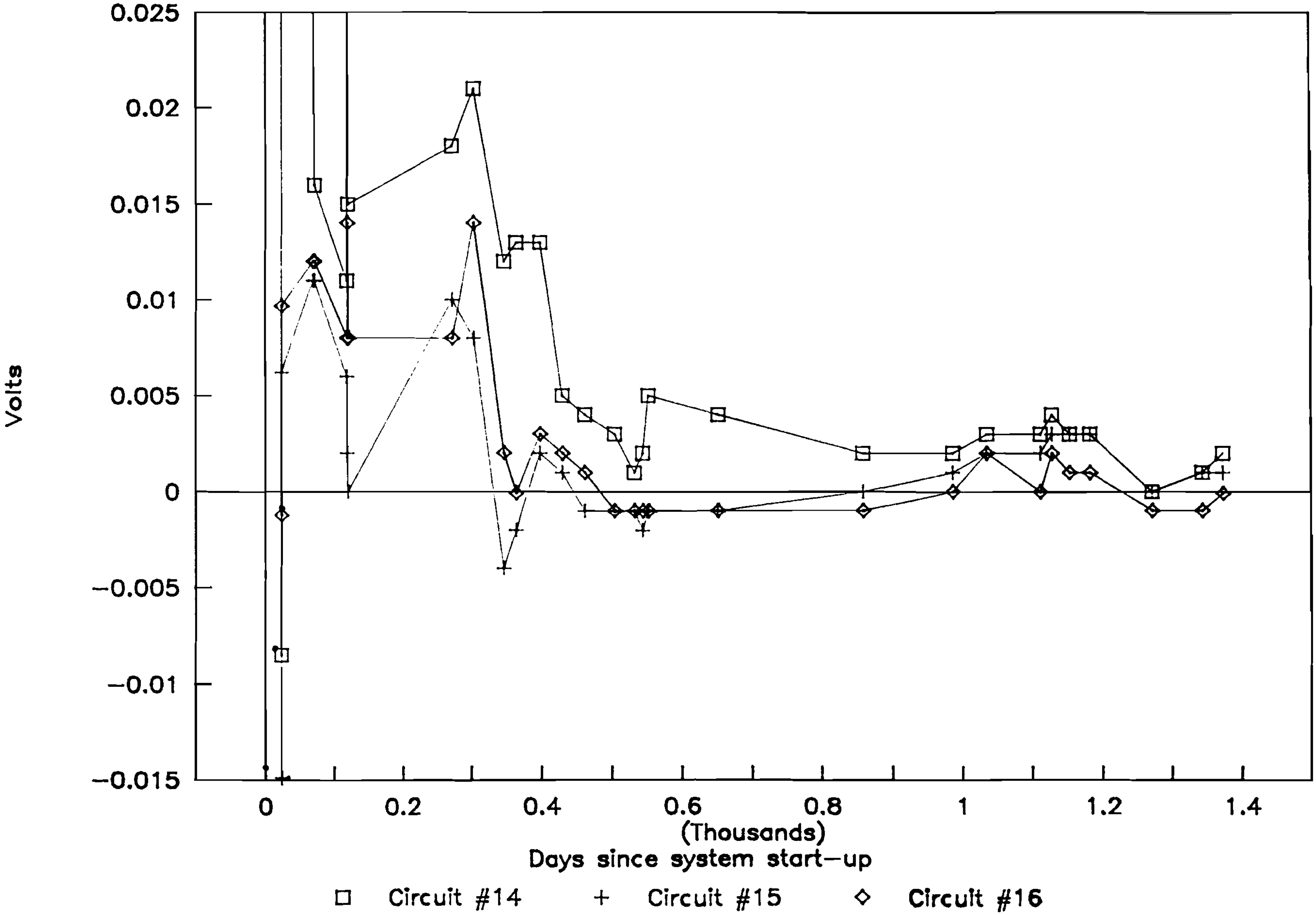


FIGURE B-24
INSTANT-OFF VOLTAGE - SPRAYED ZINC (CIRCUITS 14-16)

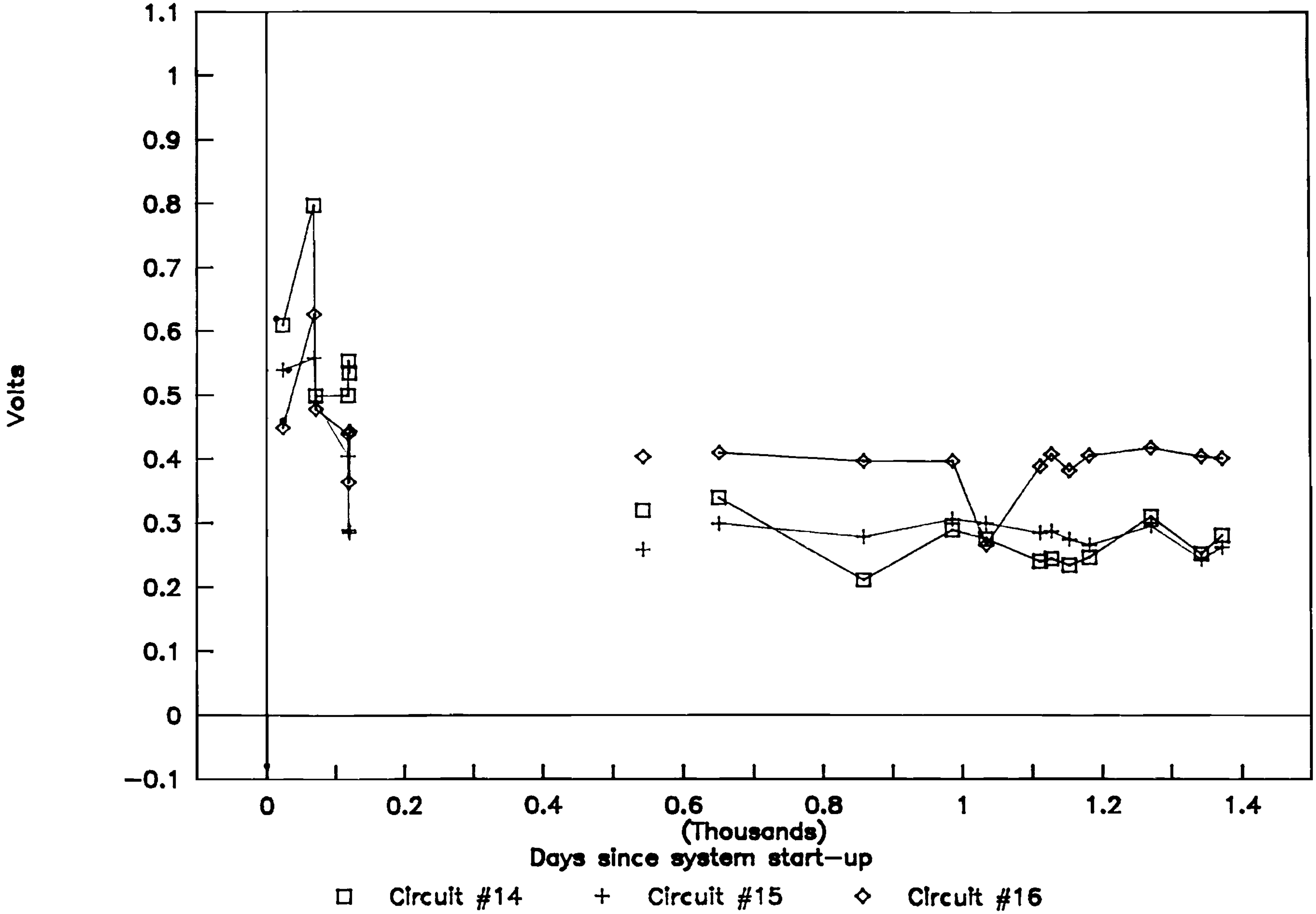


FIGURE B-25
REFERENCE CELL VOLTAGE - SPRAYED ZINC (CIRCUITS 14-16)

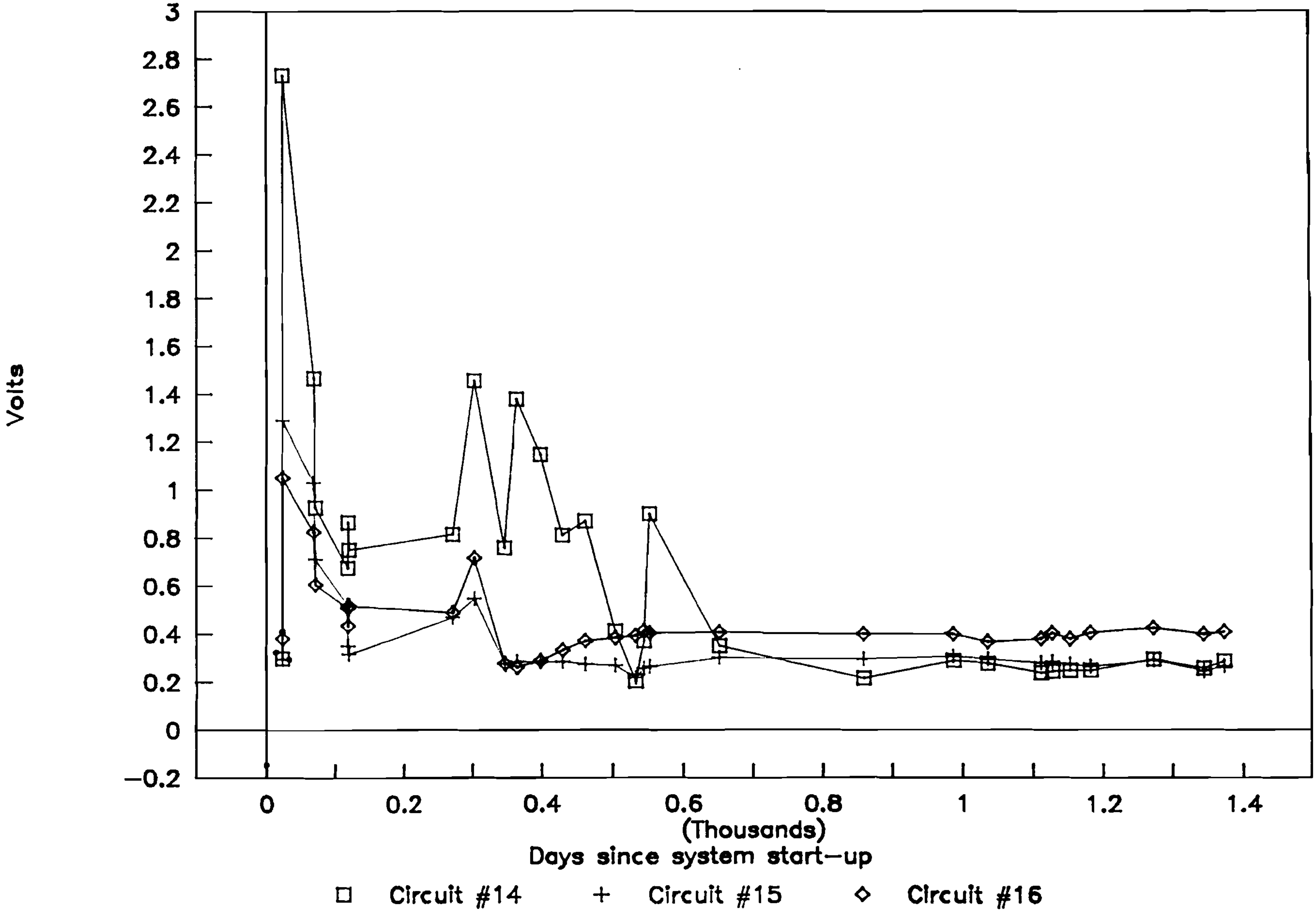


FIGURE B-26
ANODE CURRENT - CONDUCTIVE PAINT

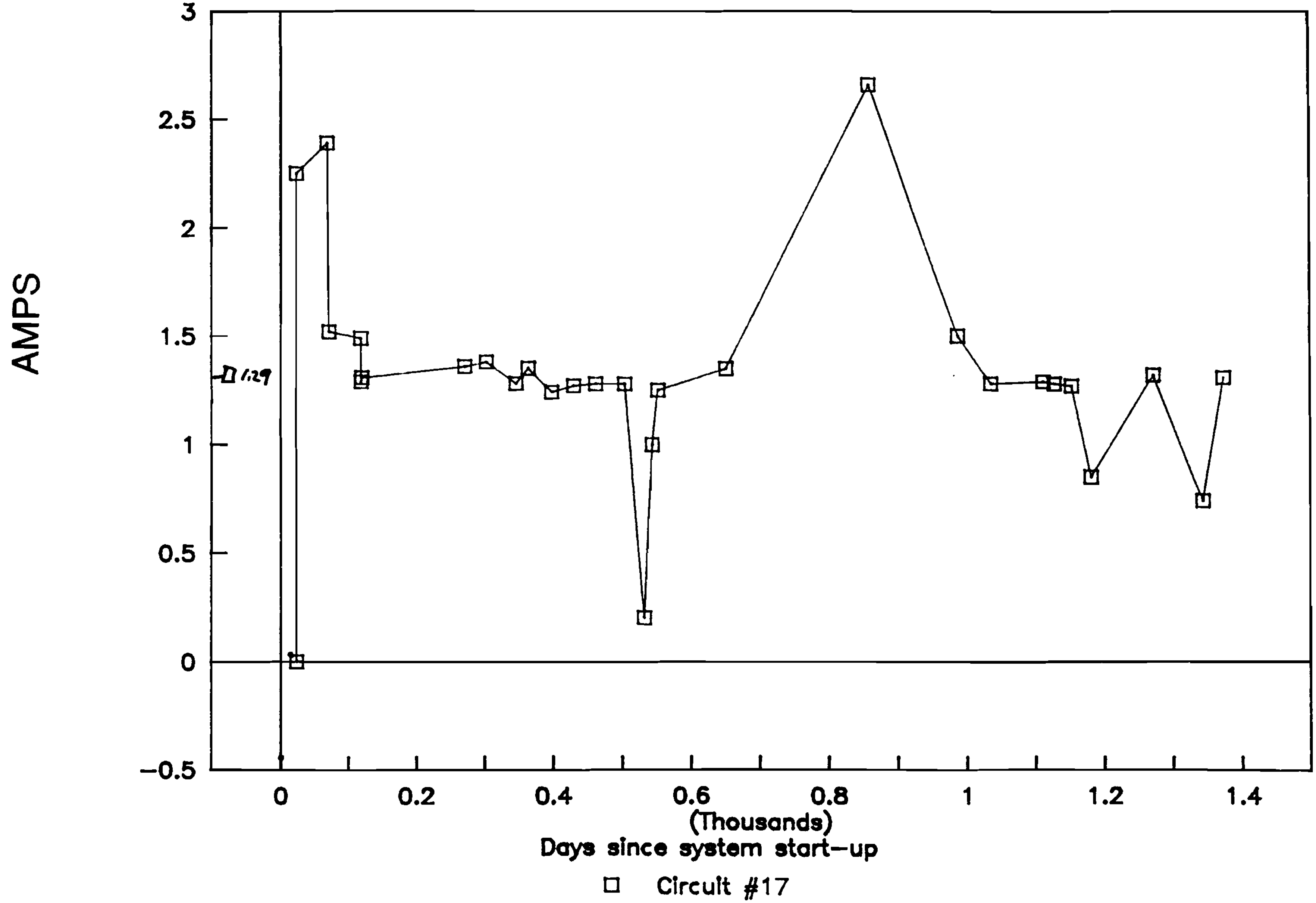


FIGURE B-27
ANODE VOLTAGE - CONDUCTIVE PAINT

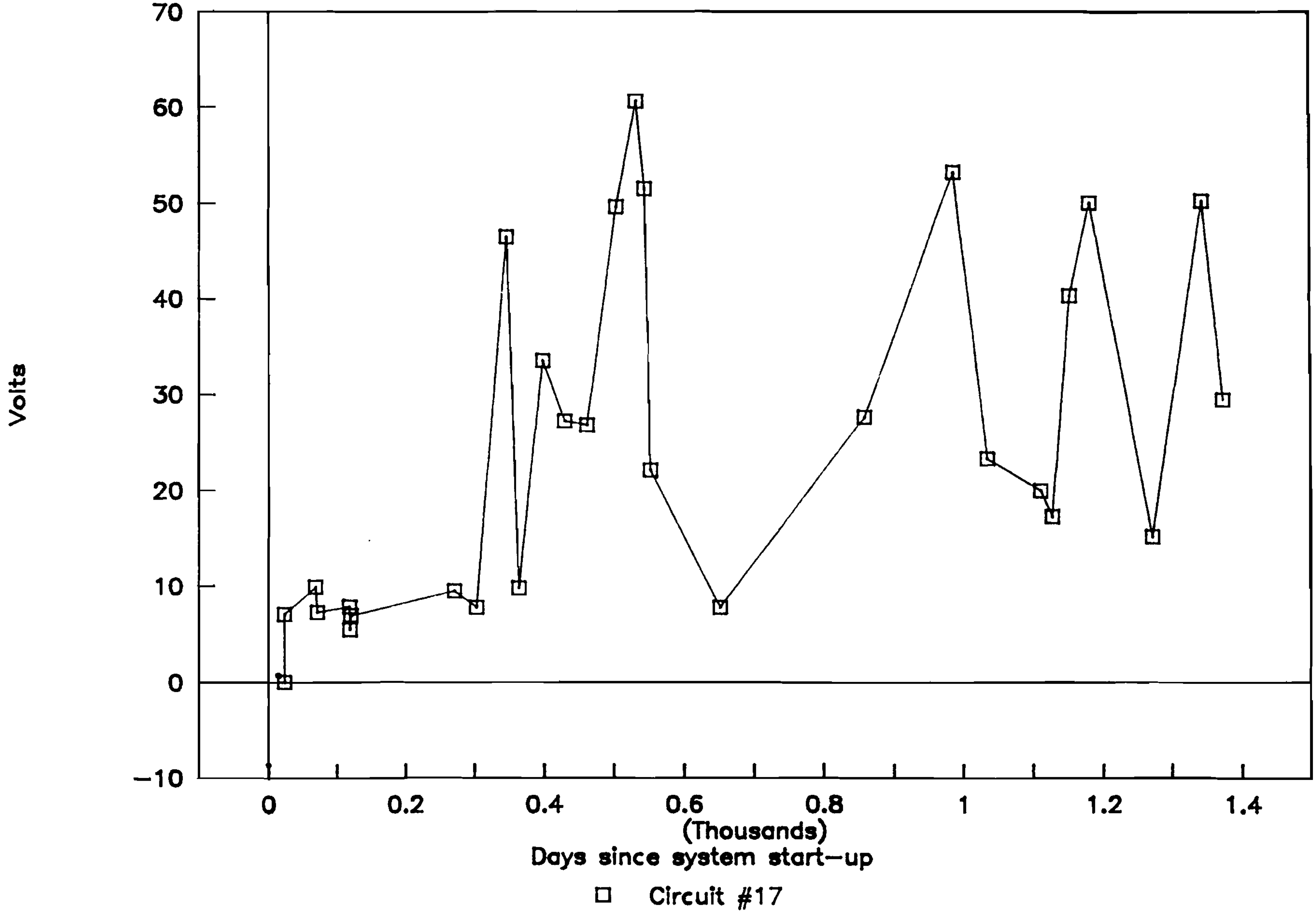


FIGURE B-28
REBAR PROBE VOLTAGE - CONDUCTIVE PAINT

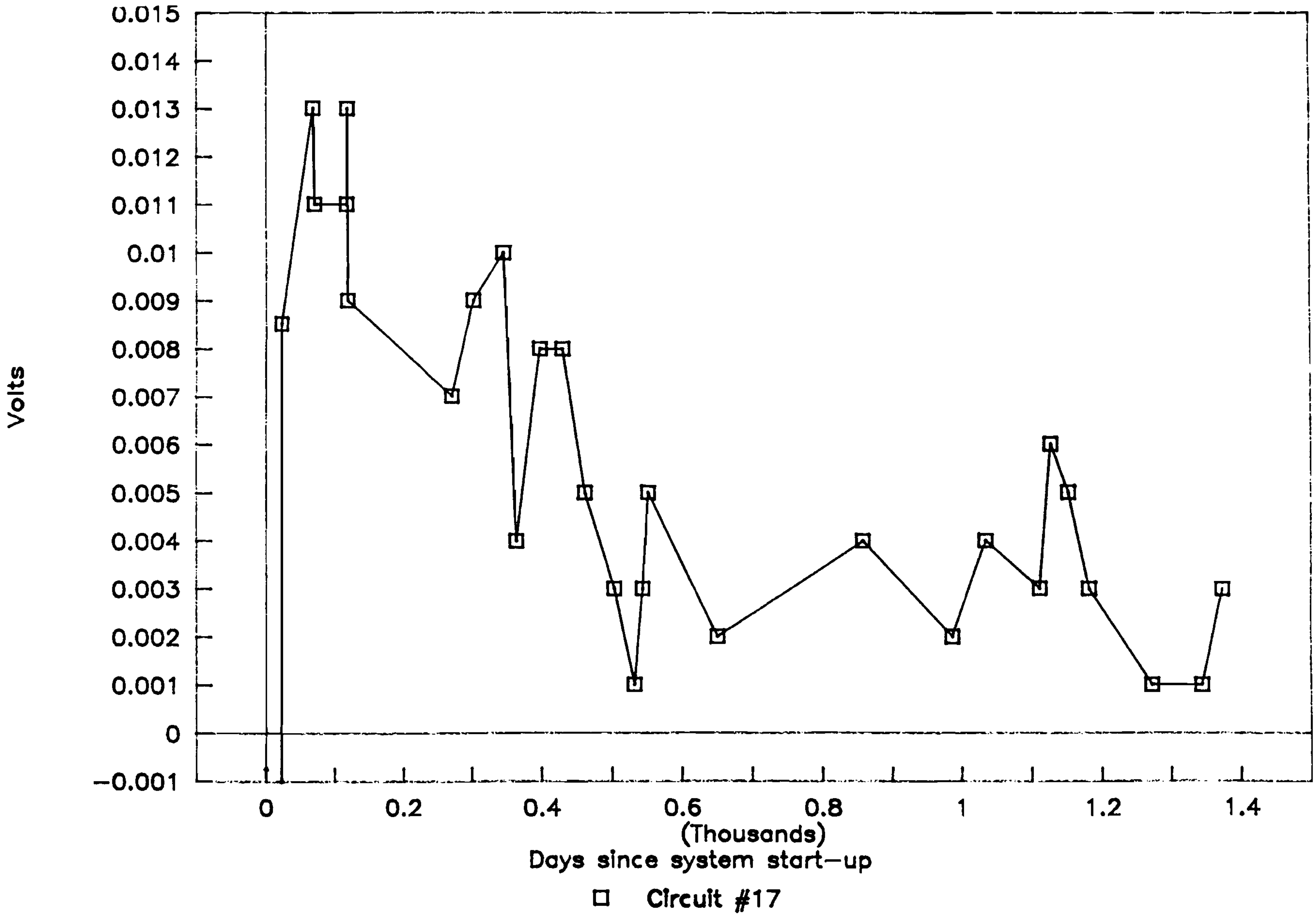


FIGURE B-29
INSTANT-OFF VOLTAGE - CONDUCTIVE PAINT

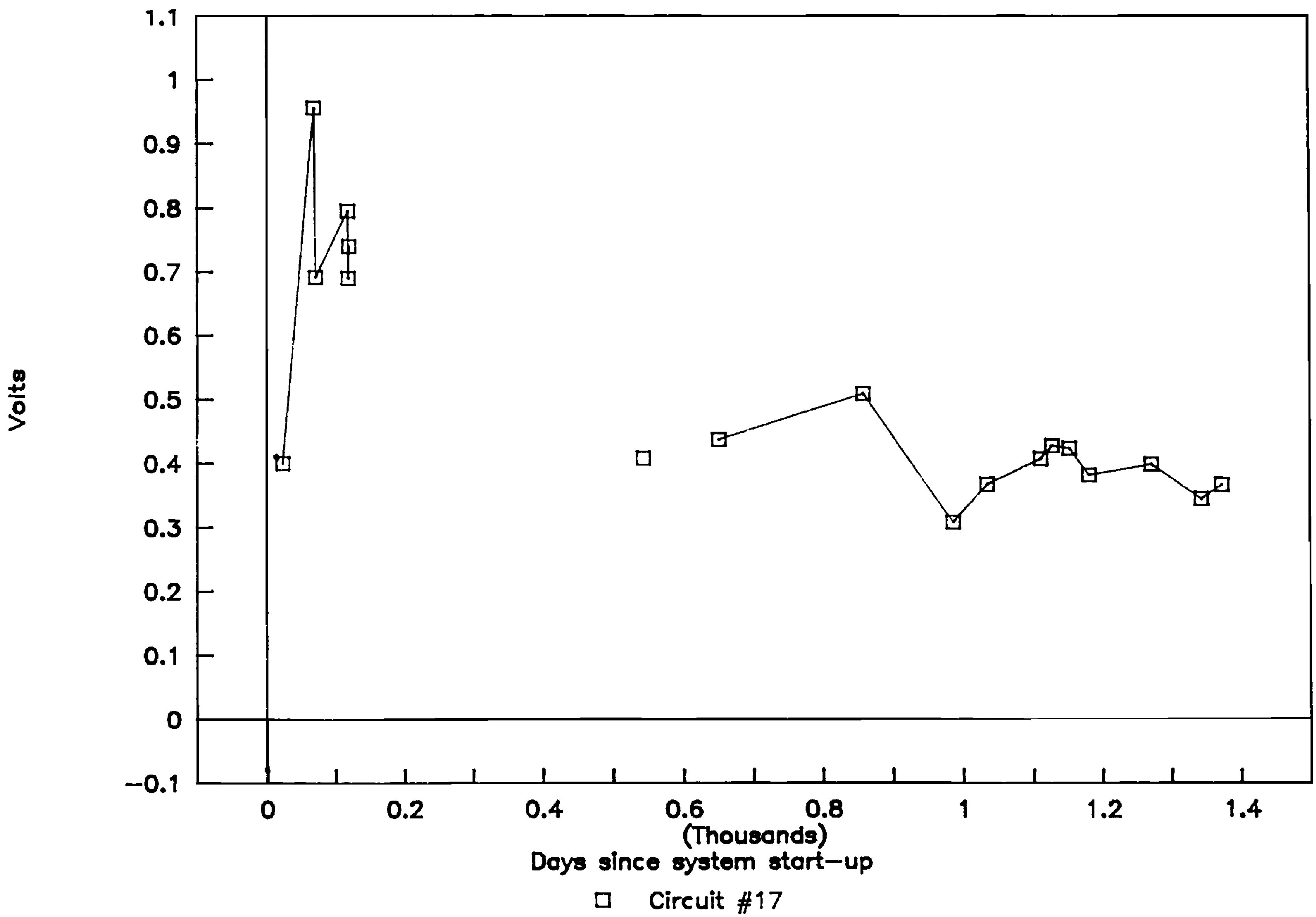


FIGURE B-30
CONDUCTANCE - ELGARD 150 MESH

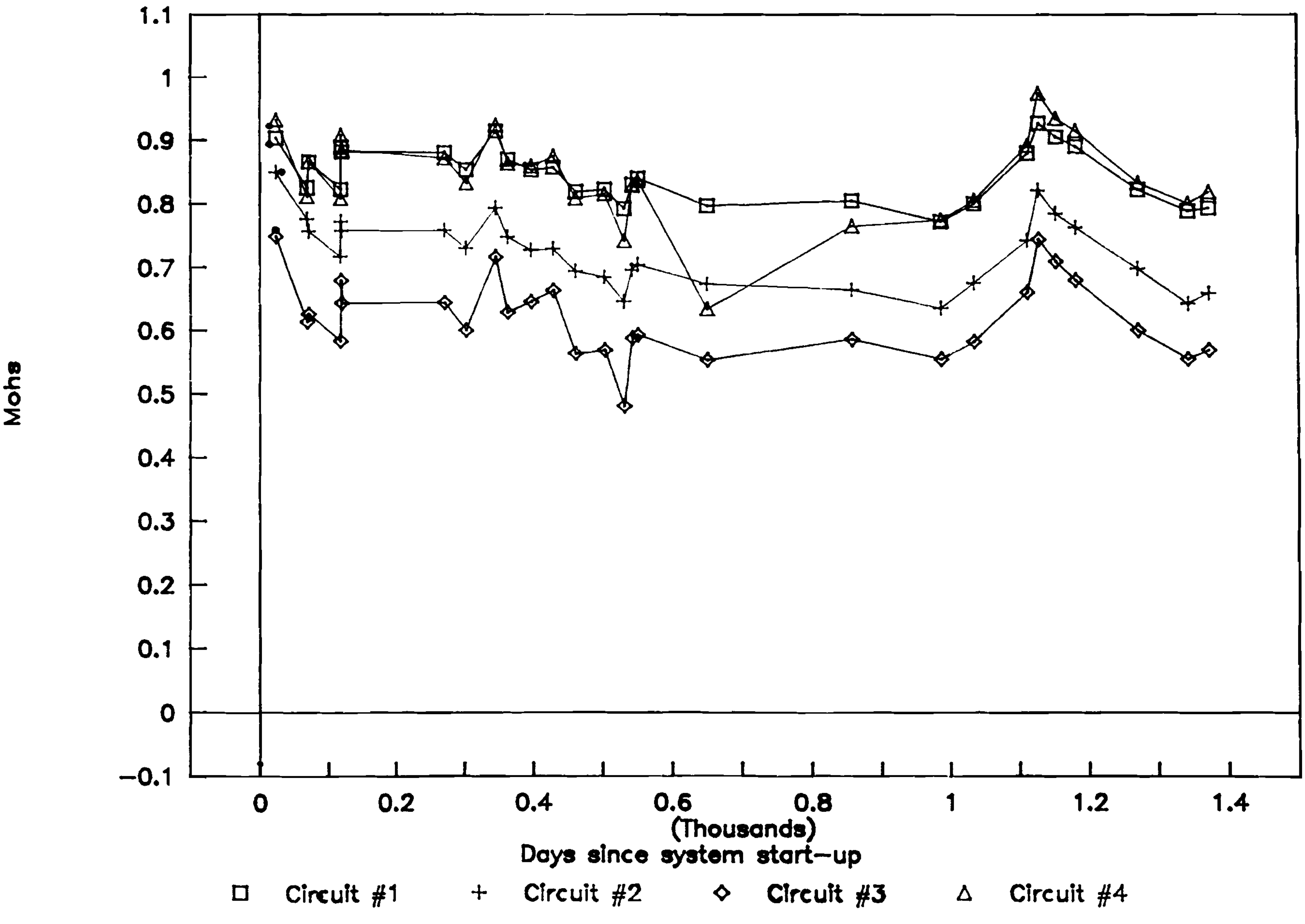


FIGURE B-31
CONDUCTANCE - RAYCHEM FEREX 100

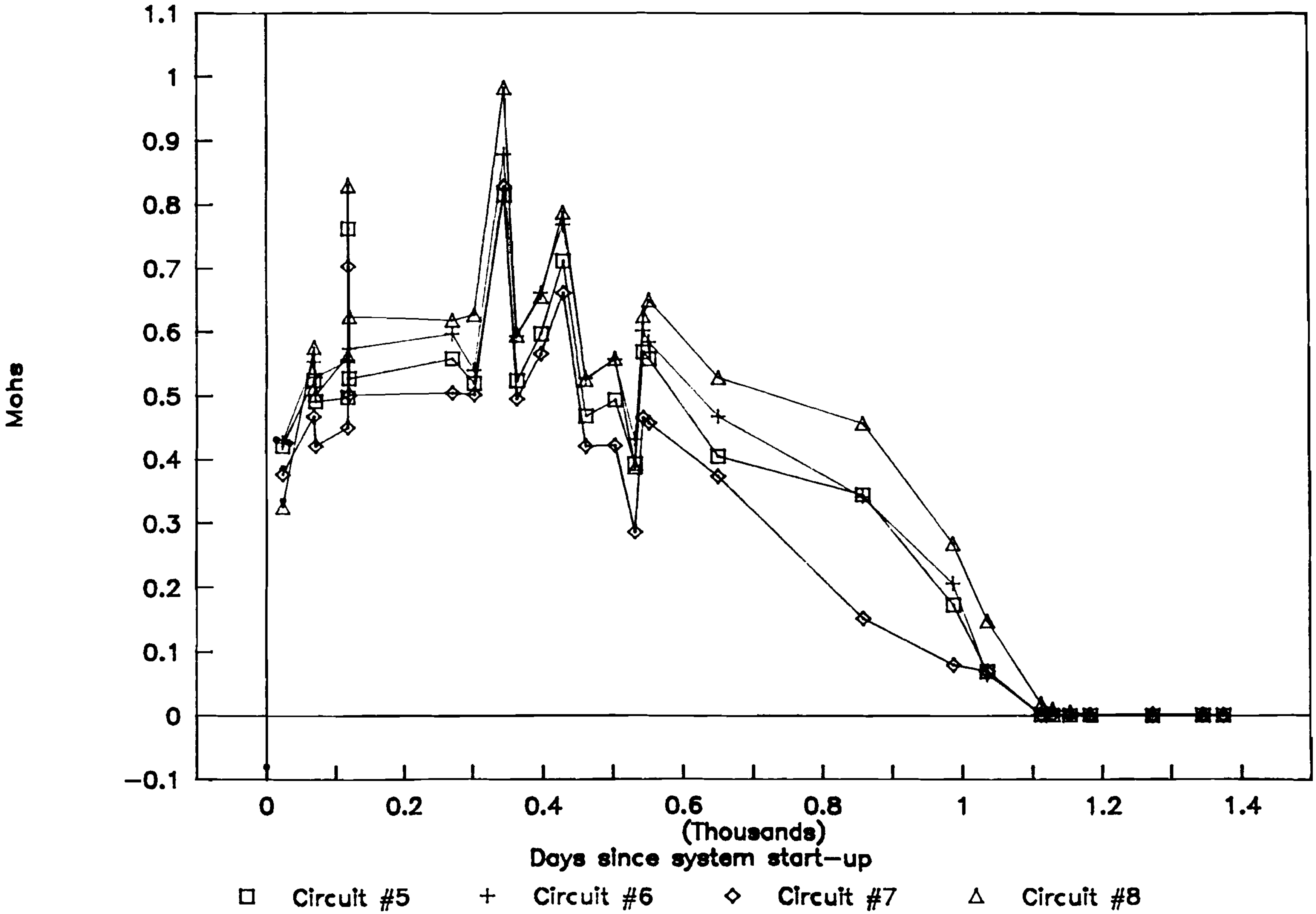


FIGURE B-32
CONDUCTANCE - RESCON POLYMER CONCRETE

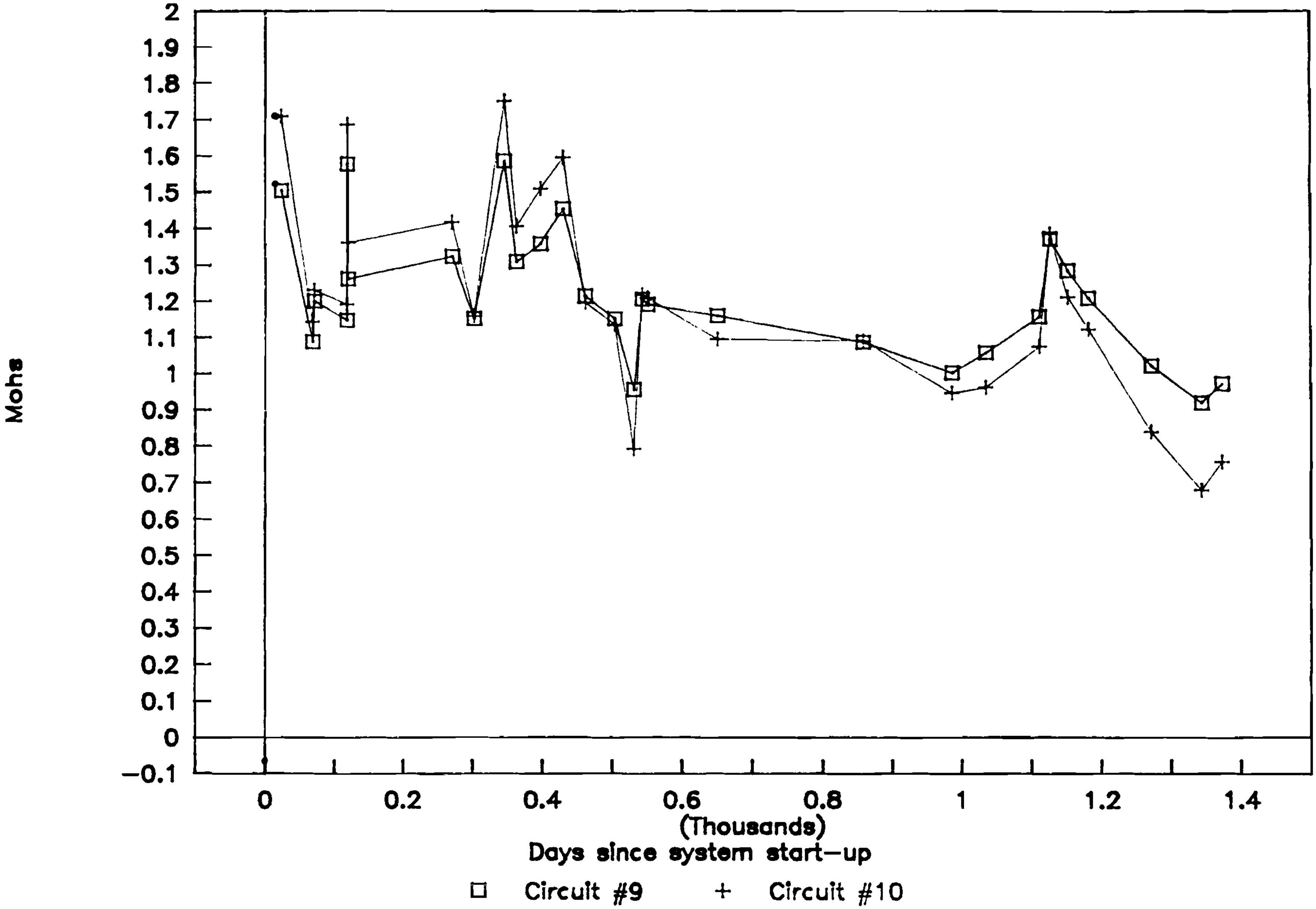


FIGURE B-33
CONDUCTANCE - SPRAYED ZINC (CIRCUITS 11-13)

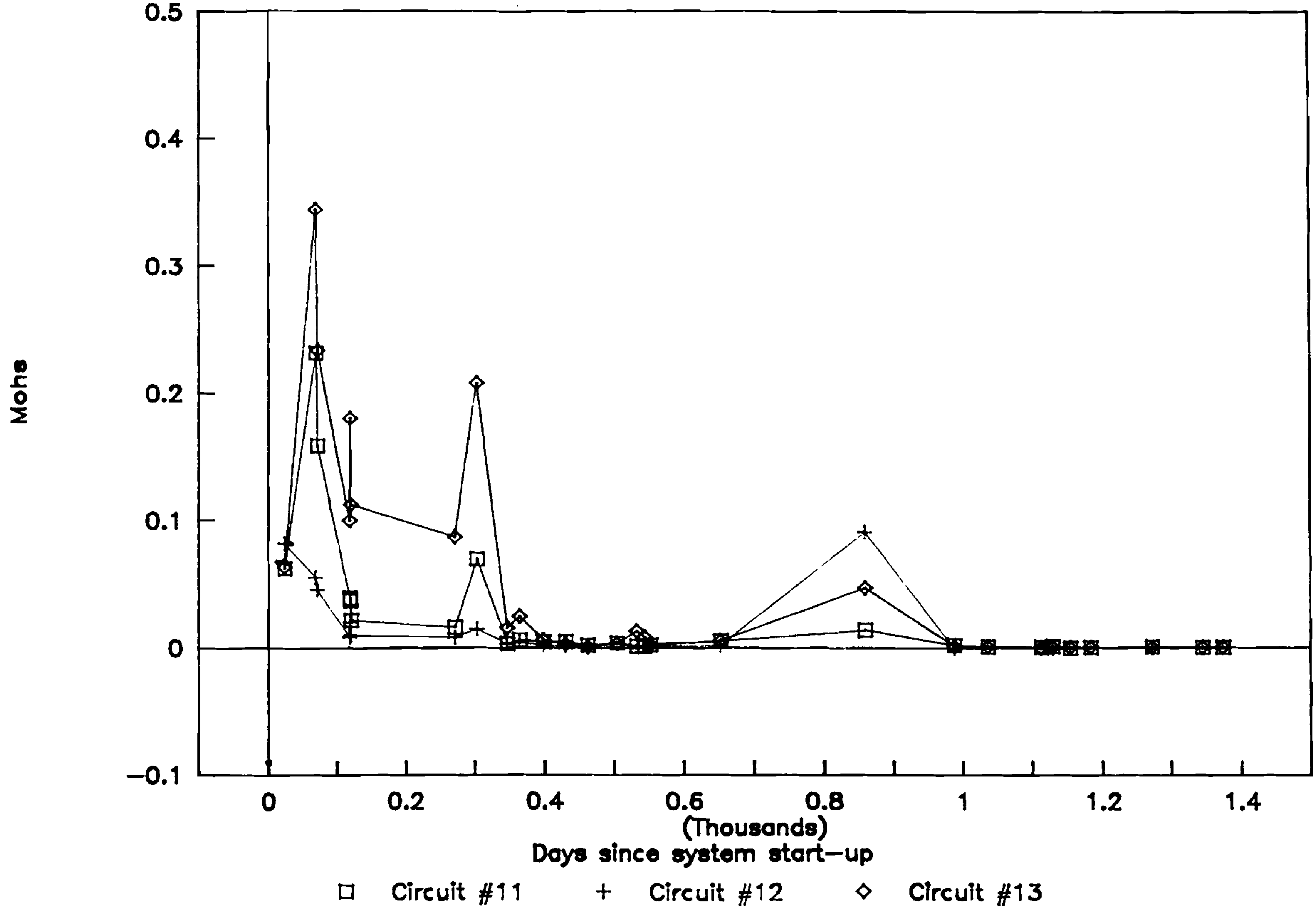


FIGURE B-34
CONDUCTANCE - SPRAYED ZINC (CIRCUITS 14-16)

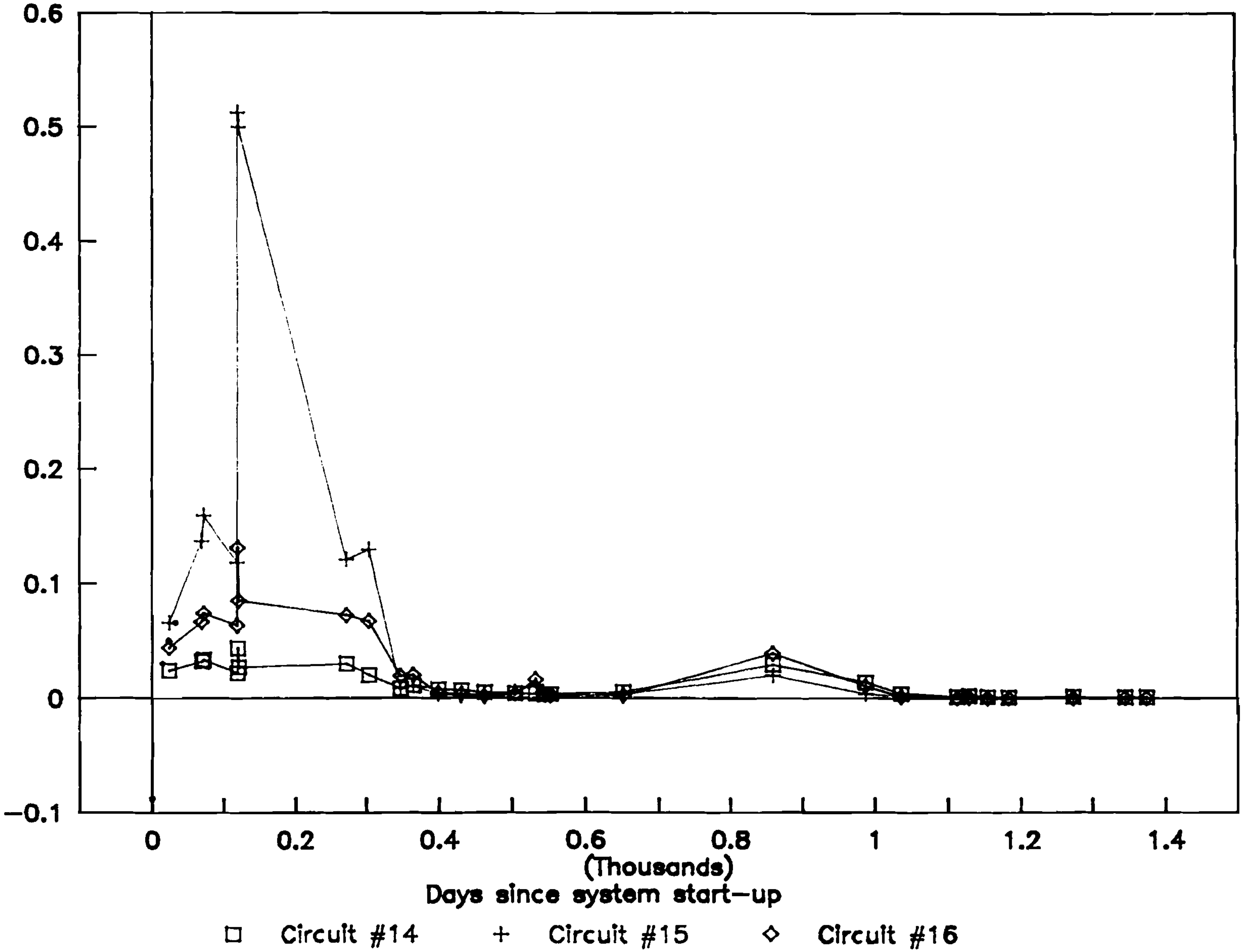


FIGURE B-35
CONDUCTANCE - CONDUCTIVE PAINT