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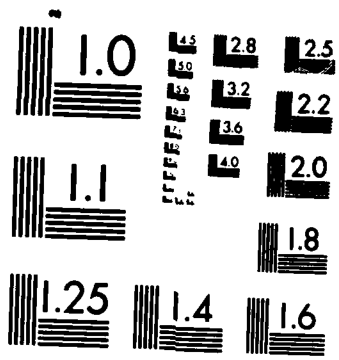
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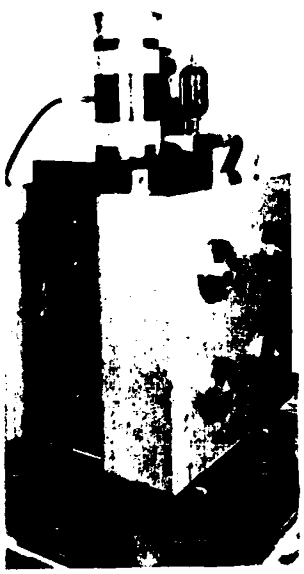

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MISCELLANEOUS PAPER GL-85-29

GEOPHYSICAL SEEPAGE STUDIES AT CENTER HILL DAM, TENNESSEE

by

Donald E. Yule, Jose L. Llopis, Michael K. Sharp

Geotechnical Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A geophysical study was performed using the self potential (SP) method. This study was directed toward detection and delineation of possible seepage paths through the embankment and/or left abutment at Center Hill Dam, Tennessee. Studies were done before and after remedial work at the dam. The initial study indicated several possible seepage zones which are interpreted as areas of low SP measurements. The follow-up survey conducted after

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20. ABSTRACT (Continued).

completion of the remedial work could not conclusively detect any changes in the SP anomalies found in the initial study. Nevertheless, there is a significant low SP anomaly on the downstream left abutment, near the embankment/dam interface. Further studies are recommended to better characterize the SP environment at this site through long-term monitoring to see if the SP anomalies are related to pool level, weather, time, etc., so that better and more definitive conclusions can be made.

Preface

A geophysical seepage study was authorized by the US Army Engineer District, Nashville, under IAO No. 82-44 and IAO No. 85-0010, dated 19 July 1982 and 9 October 1984, respectively.

Field tests were conducted during the periods 16-21 August 1982 and 23-26 November 1984. Messrs. S. S. Cooper, D. E. Yule, J. L. Llopis, D. H. Douglas, M. K. Sharp, and Lt. S. G. Sanders of the Field Investigations Group, (FIG), Earthquake Engineering and Geophysics Division (EEGD), Geotechnical Laboratory (GL), US Army Engineer Waterways Experiment Station (WES), were members of the field parties who conducted this study. The analysis phase of the study was performed by Messrs. Yule, Cooper, and Llopis. The work was performed under the direct supervision of Mr. J. R. Curro, Jr., Chief, FIG, EEGD, GL, under the general supervision of Dr. A. G. Franklin, Chief, EEGD, GL, and Dr. W. F. Marcuson III, Chief, GL. This report was prepared by Messrs. Yule, Llopis, and Sharp.

Director of WES was COL Allen F. Grum, USA. Technical Director was Dr. Robert W. Whalin.

Contents

Conversion Factors, Non-SI to SI (Metric)
Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
miles (US statute)	1.609347	kilometres

GEOPHYSICAL SEEPAGE STUDIES AT CENTER HILL DAM, TENNESSEE

Background

1. The US Army Engineer District, Nashville (ORN), in conjunction with their special engineering investigation of the earth embankment and foundation of Center Hill Dam, located as shown in Figure 1, requested the US Army Engineer Waterways Experiment Station (WES) to conduct a post-remedial geophysical study of the left abutment and earthen embankment. The WES study was to be directed toward detection and delineation of possible seepage paths through the embankment and/or abutment using the self potential (SP) method. A pre-remedial study was performed in August 1982 and reported by Cooper.* The results were submitted to ORN for use in planning their remedial work on the dam. WES was then requested to perform this follow-up study to compare the earlier results with those after the remedial work was completed.

2. The followup study was performed by a three-man WES field crew during the period 23-26 November 1984. The field crew consisted of Messrs. D. E. Yule, J. L. Llopis, and D. H. Douglas, Earthquake Engineering and Geophysics Division, Geotechnical Laboratory, WES.

Purpose and Scope

3. This report documents the followup SP survey and compares the results with the initial survey performed. Data from both SP surveys and their analyses are presented. In order to make this followup survey as useful as possible for comparison of the two data sets, yet take advantage of improved field methods derived from experience gained in the intervening 2 years between surveys, the following scope of work was implemented. The survey covered the same stations as was previously used, when possible, with readings taken shortly after electrode placement. The same type of rods and same reference electrode location were used which would duplicate the initial test

* Cooper, S. S. 1982. "Geophysical Studies at Center Hill Dam, Tennessee," Memorandum for Record, US Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi 39180-0631.

conditions. It has been noted that at some sites SP readings change with time as electrical equilibrium is being established between the ground and electrode. This phenomenon was investigated to see if this would be a problem at this site. Several lines were read initially and then again 12-24 hours later. Due to time and funding limitations, all lines could not be read the second time. Location of the SP lines are shown in Figures 2 and 3 for these surveys.

Data Presentation

4. The test results for SP lines 1 through 8 are shown in Figures 4 through 11, respectively, and Table 1. Each figure consists of two plots. Up to three sets of data are displayed on each plot to show the different sets of readings that were actually taken for that line. The three sets of readings are: readings taken in August 1982, shortly after electrode placement (I), readings taken in November 1984, shortly after electrode placement (I), and readings taken in November 1984 after allowing electrodes to stabilize (D). The symbols are consistent for all the figures. The upper plot in a figure is the raw data (SP readings) versus stations. The stations correspond with the stations for that line as shown in Figures 2 and 3. The separation between stations is 50 ft.* The area between the two readings taken in November 1984 is shaded to more clearly distinguish between these readings and the ones taken in August 1982. This shading also helps show the trend between the readings resulting from the effect of electrode stabilization with time. The plot at the bottom of each figure shows the data presented again after processing. The processing consisted of finding the average reading for each set of data and then subtracting this from each reading of that set. In this plot the zero millivolt (mv) axis represents the average value for all sets of data and provides a way of comparing the data sets with the effect of time of reading removed. This assumes that the time effect is relatively uniform throughout each line and accounts for a base datum (line average) on which data is superimposed. The actual value of the zero axis for each set of data can be found in Table 1.

5. Table 1 summarizes some statistics about the data in relation to the line location and time of reading. Because the interpretation of SP data is

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

not fully developed, all factors and their effects are not known; therefore, a statistical analysis of the data is a consistent method for identification of anomalies which might be associated with seepage zones. The line averages can be used to discern general trends between data sets. These trends are further amplified by listing the relative change in these values. The standard deviation in this case gives a measure of the scatter of the data for each line and is used to help decide what is a significant low SP reading.

Discussion of Results

6. In the interpretation of the readings taken in August 1982, SP values less than -200 mv were chosen as zones of possible seepage and readings less than -300 mv were further emphasized as significant anomalies. In comparing the readings from 1982 to those taken in 1984, two approaches were taken; one, a direct comparison between the initial 1982 and 1984 readings and two, comparing the 1984 readings after the time drift was removed with the 1982 readings.

7. The results for line SP-1 (upper plot in Figure 4) in August 1982 showed low anomalies at Stations 1, 3-5, 15, 17, 19-20, and 23-29 based on the -200 mv criteria. The data taken in November 1984 showed a very negative trend (less than -200 mv) but was the data obtained after allowing the electrodes to stabilize. From looking at the line averages in Table 1, readings can drift as much as -166 mv, therefore the much more negative readings are not surprising. This does complicate the issue then of what is significant. Looking at the bottom plot it would seem that readings that deviate more than 150 mv from the line average might be significant. In this case Stations 25-30 still exhibit a very negative potential and, therefore, would be possible seepage locations. The high positive reading at Station 11 corresponds with being underneath power lines.

8. The results for line SP-2 (Figure 5) in August 1982 exhibited low values at Stations 9 and 11 (<200 mv). The data taken in November 1984 is again much more negative with very low readings (<350 mv) at Stations 3 and 5 using the 150-mv criterion as in paragraph 7, it appears Station 5 is an anomaly location.

9. The results for line SP-3 (Figure 6) in August 1982 show a low SP area extending from Station 5 to Station 12 which agrees well with the November 1984 results. Looking at the bottom plot the results match very well once a correction was made for time effect. Using the 150-mv criteria only Stations 5 and 10 approach the significantly low anomalous value criteria.

10. The results from August 1982 readings of line SP-4 (Figure 7) show low SP values at Stations 2 and 10-17. From the November 1984 data set, Stations 1, 4, 8-16, show low SP values. From the shading of the 1984 readings the downward shift of SP with time is clearly shown in the top plot and in the bottom plot the shaded portion is greatly reduced showing that the time effect is fairly uniform and can be removed using the line average. It appears that Stations 9 and 15 still exhibit anomalous values when judged by the 150-mv criteria.

11. The results for line SP-5 (Figure 8) showed a low SP area between Stations 13-18 and 23 in the August 1982 data set. The data from the November 1984 readings had three low SP regions at Stations 9, 15-17, and 25-29. The bottom plot shows that SP anomalies appear to exist at Stations 9, 16, and 27-28.

12. The results from the August 1982 survey, line SP-6 (Figure 9) show a low SP region almost throughout the line with the line average being -197 mv. However, the first November 1984 readings show a more positive trend with a line average of -43 mv which then drifted down over 24 hours to values that agree well with the August 1982 data set. Referring to the bottom plot, Stations 18 and 20 exhibit low SP readings for the November 1984 data.

13. The results from the August 1982 survey, line SP-7 (Figure 10) show SP areas at Stations 3, 10-11, 48-50, and 56. The readings taken in 1984 show, on average, about the same as the August 1982 readings. After correcting for time effects the data looks fairly random about the line average with low readings occuring at Stations 25, 33-34, 40, and 48.

14. The data from line SP-8 (Figure 11) in August 1982 indicated a low value at Station 7. The line run in November 1984 was parallel to the 1982 line but instead of at the rivers edge it was conducted at the grass/rip-rap boundary and was designated SP-8A. The line 8A data was more negative with slightly low SP values noted at Stations 2 and 5.

15. Based upon the two reading sets (1982, 1984) there is still a low SP area existing at the embankment/dam interface of the downstream left abutment. This area is located between Stations 25-29 on line 1 and Stations 9-17 on line 4 and is shown in Figure 2. Other stations still showed low SP readings in the study but were singular in nature and are considered nonsignificant because of the small data base obtained at the site.

Conclusions and Recommendations

16. In general the comparisons between the SP readings taken in August 1982 and November 1984 showed the 1984 values to be more negative. This was probably due to letting the electrodes come to equilibrium. When this time effect was removed and the two data sets could be compared, most of the same trends were apparent in both. This leads one to consider re-evaluating the significance criteria for anomalous SP values that might be related to seepage and/or to conclude that the site remained basically unchanged over the time between readings. However, even applying stricter criteria there still appears to be an anomalous area on the downstream left abutment, near the embankment/dam interface.

17. In retrospect, it appears that better results could have been obtained by monitoring over an extended period with permanent arrays. This approach should still be considered. Doing this would allow correlation with time, weather, and pool level, thus allowing cause/effect relations to be studied. Especially interesting would be to see if any of the SP readings were being driven by pool level. Then a strong conclusion could be drawn relating the seepage to the reservoir or other means.

Table 1

Line	Reading Time	Line Average	Change From:	Aug 82	Nov 84	Standard Deviation
SP-1	I* Aug 82	-229		126		
	D** Nov 84	-359	-120	167		
SP-2	I Aug 82	-131		70		
	D Nov 84	-224	-93	114		
SP-3	I Aug 82	-223		72		
	D Nov 84	-296	-73	74		
SP-4	I Aug 82	-199		77		
	I Nov 84	-248	-51	103		
	D Nov 84	-253	-154	-105		127
SP-5	I Aug 82	-122		87		
	I Nov 84	-105	+17	88		
	D Nov 84	-203	-81	-98		106
SP-6	I Aug 82	-197		47		
	I Nov 84	-43	+154	55		
	D Nov 84	-209	-12	-166		69
SP-7	I Aug 82	-117		72		
	D Nov 84	-111	+6	105		
SP-8	I Aug 82	-121		39		
8A	D Nov 84	-159	-38	103		

Reading Set	Total Averages
I Aug 82	-167
I Nov 84	-132
D Nov 84	-139

* I - Reading immediately after electrode placement
** D - Reading 12-24 hours after electrode placement

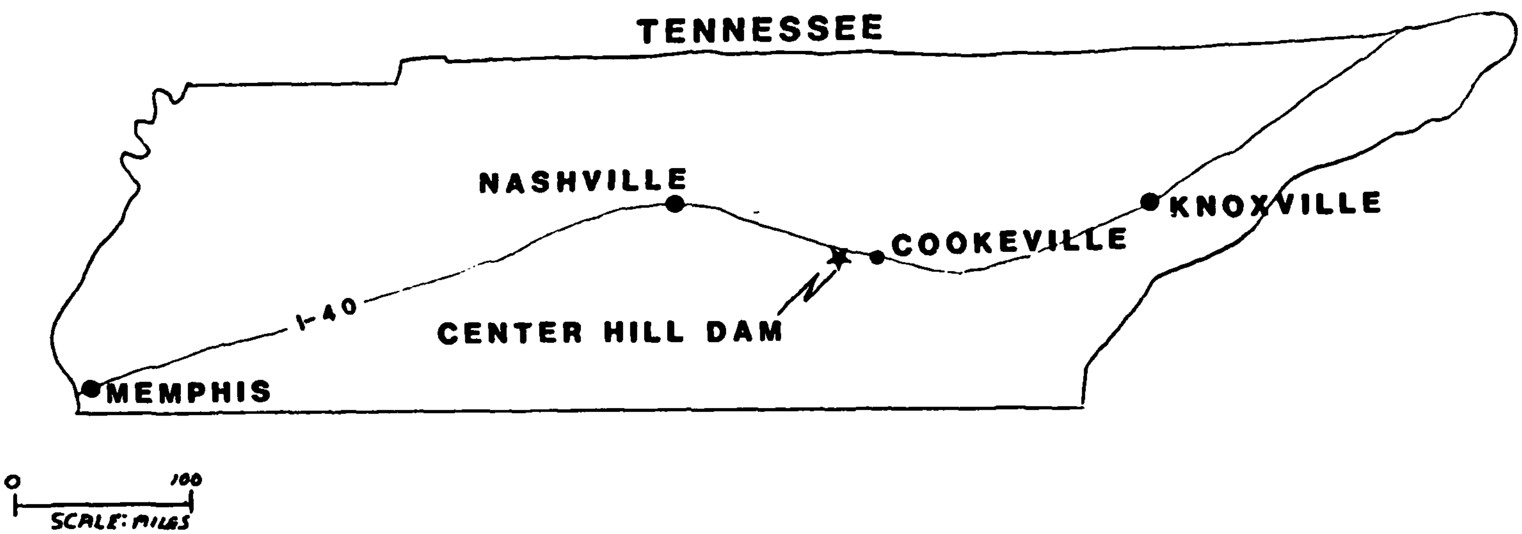

Figure 1. Location Map

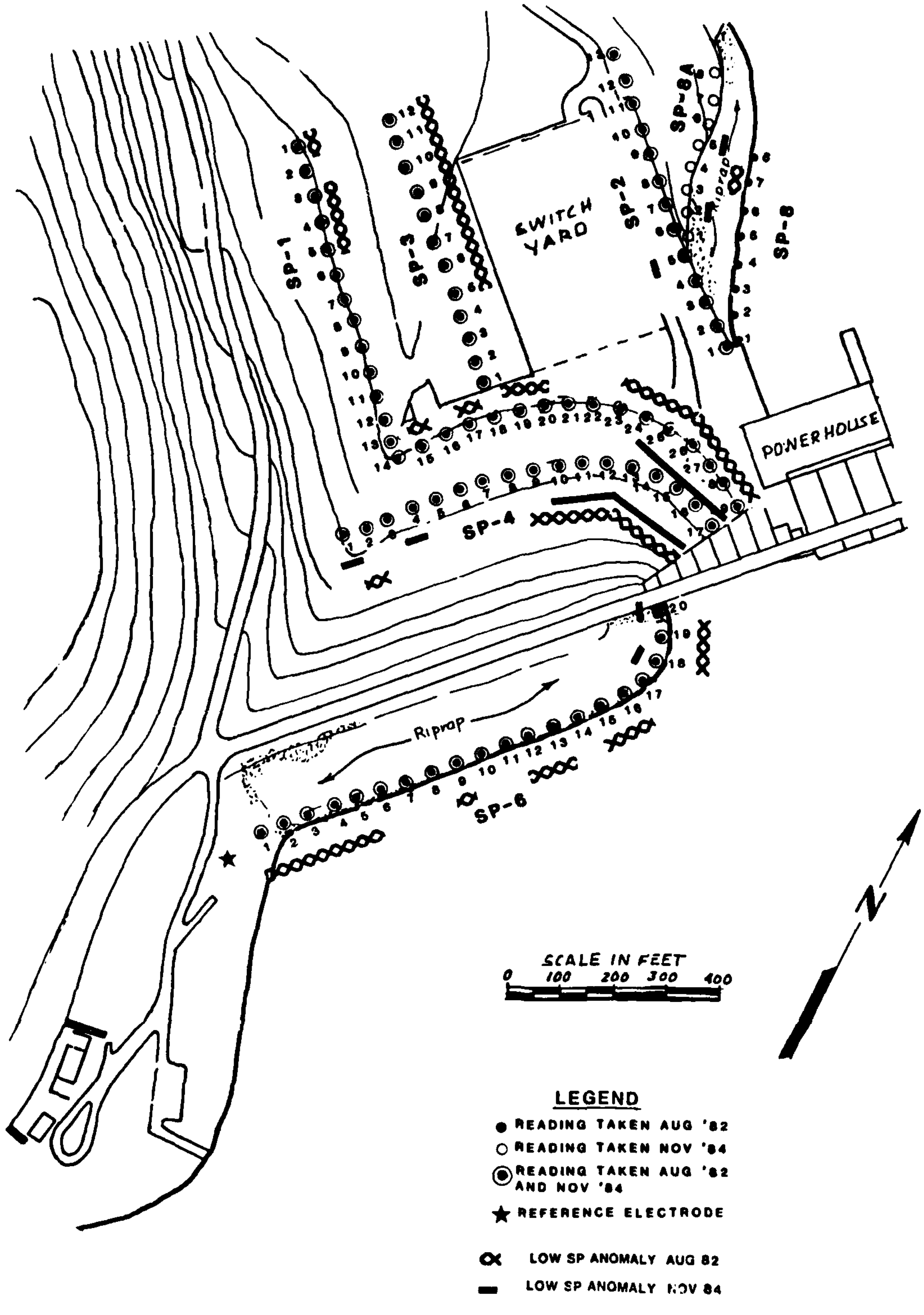

Figure 2. SP line locations and survey results for Center Hill Dam

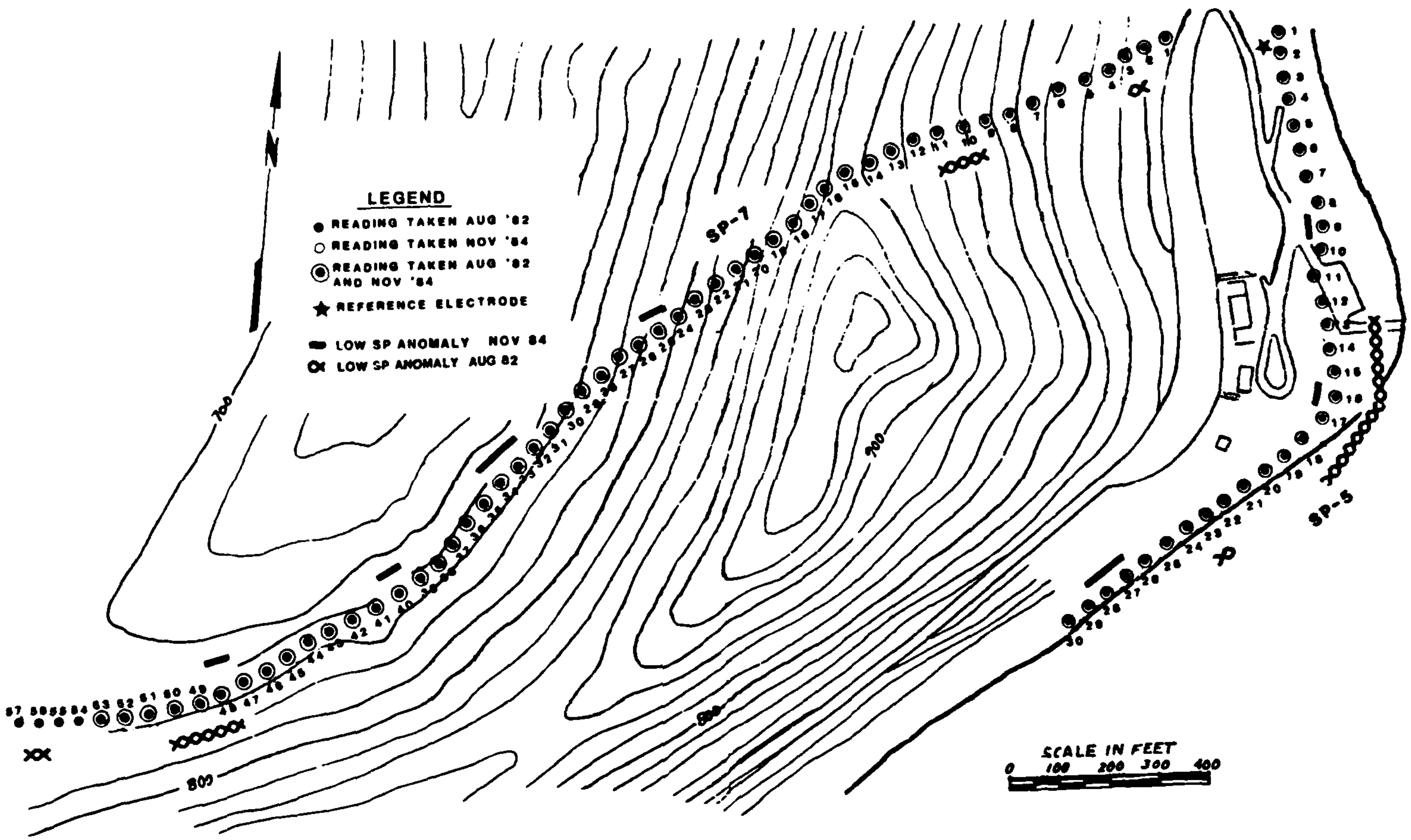

Figure 3. SP line locations and survey results for Center Hill Dam left abutment

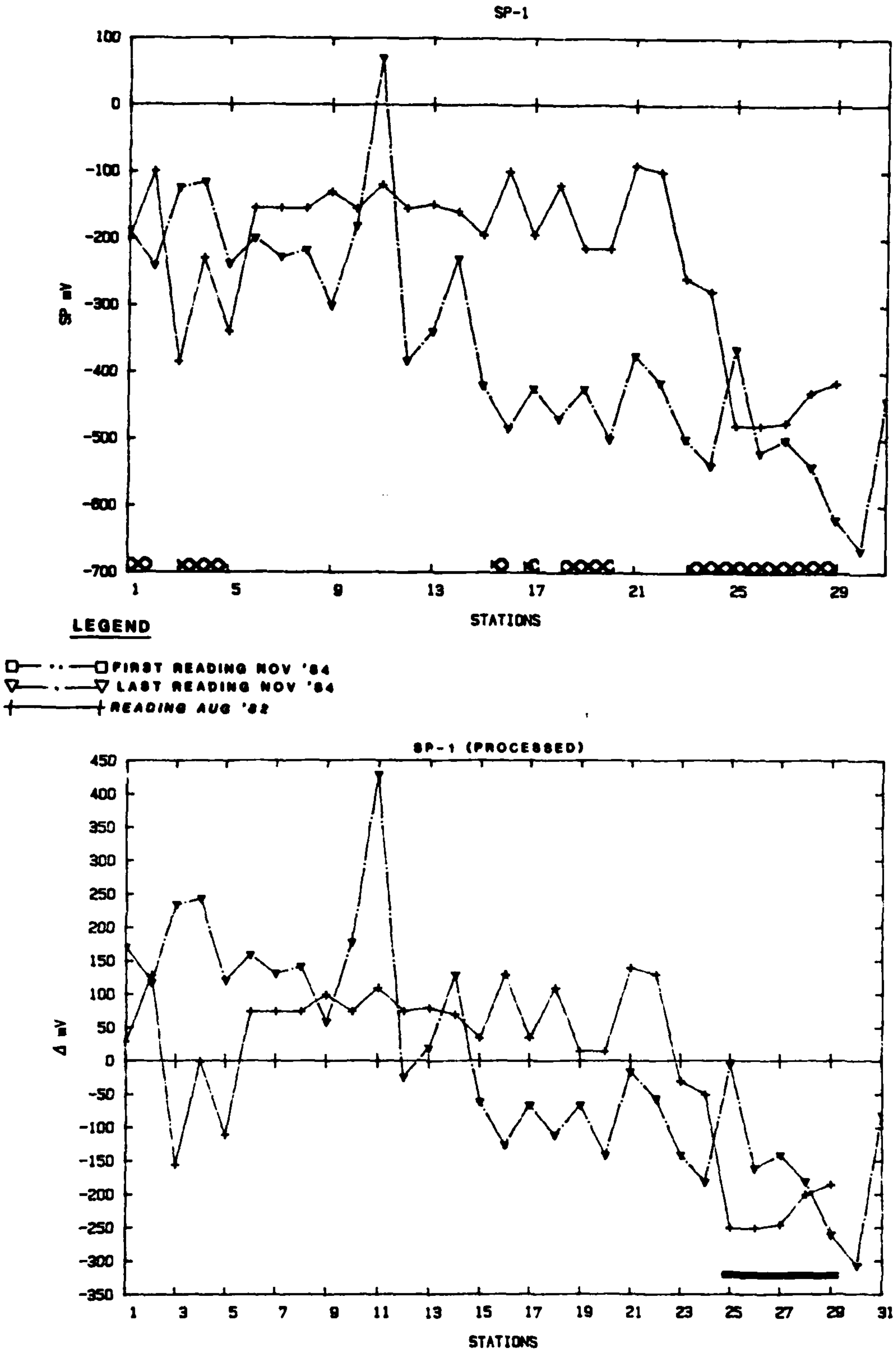

Figure 4. Self potential data for line SP-1

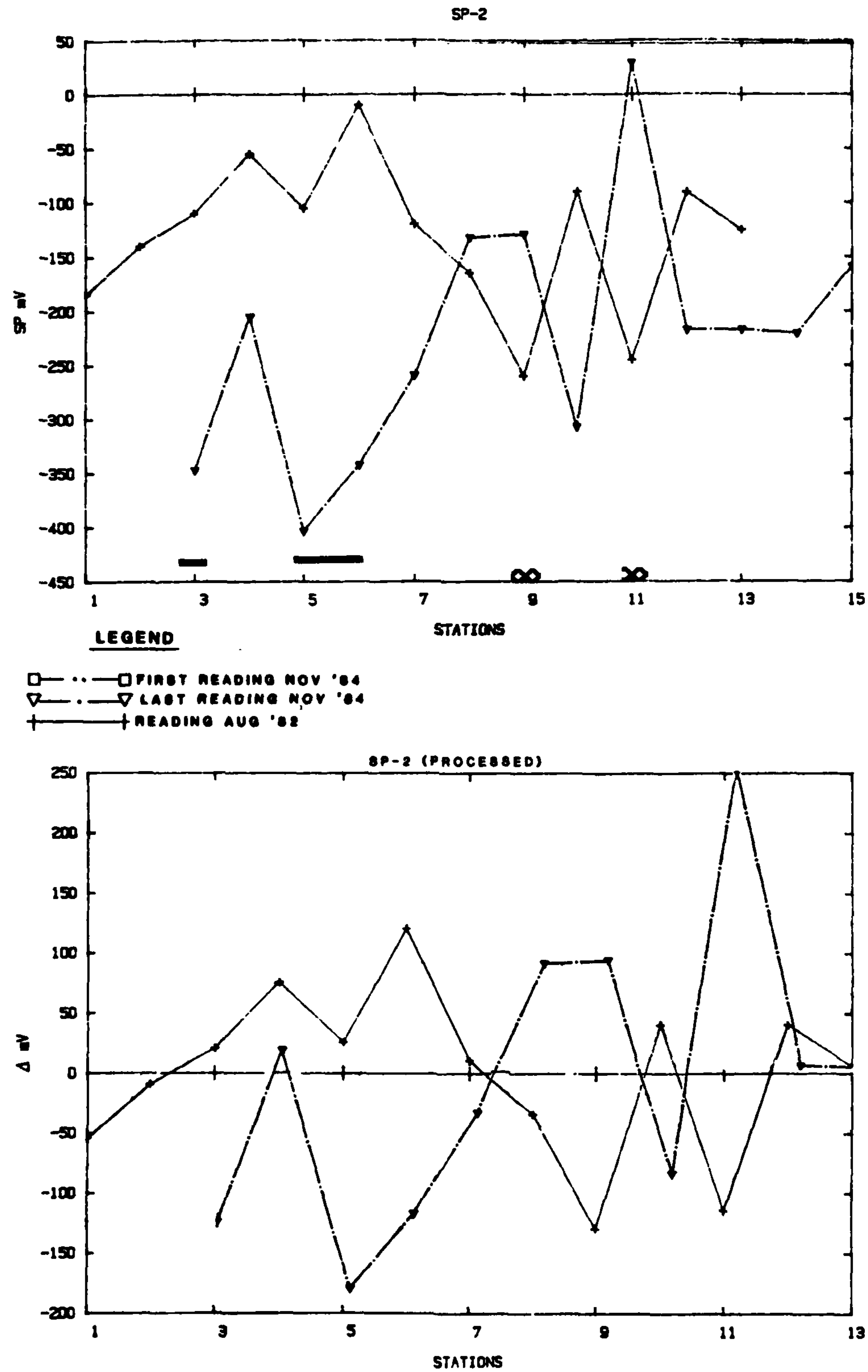

Figure 5. Self potential data for line SP-2

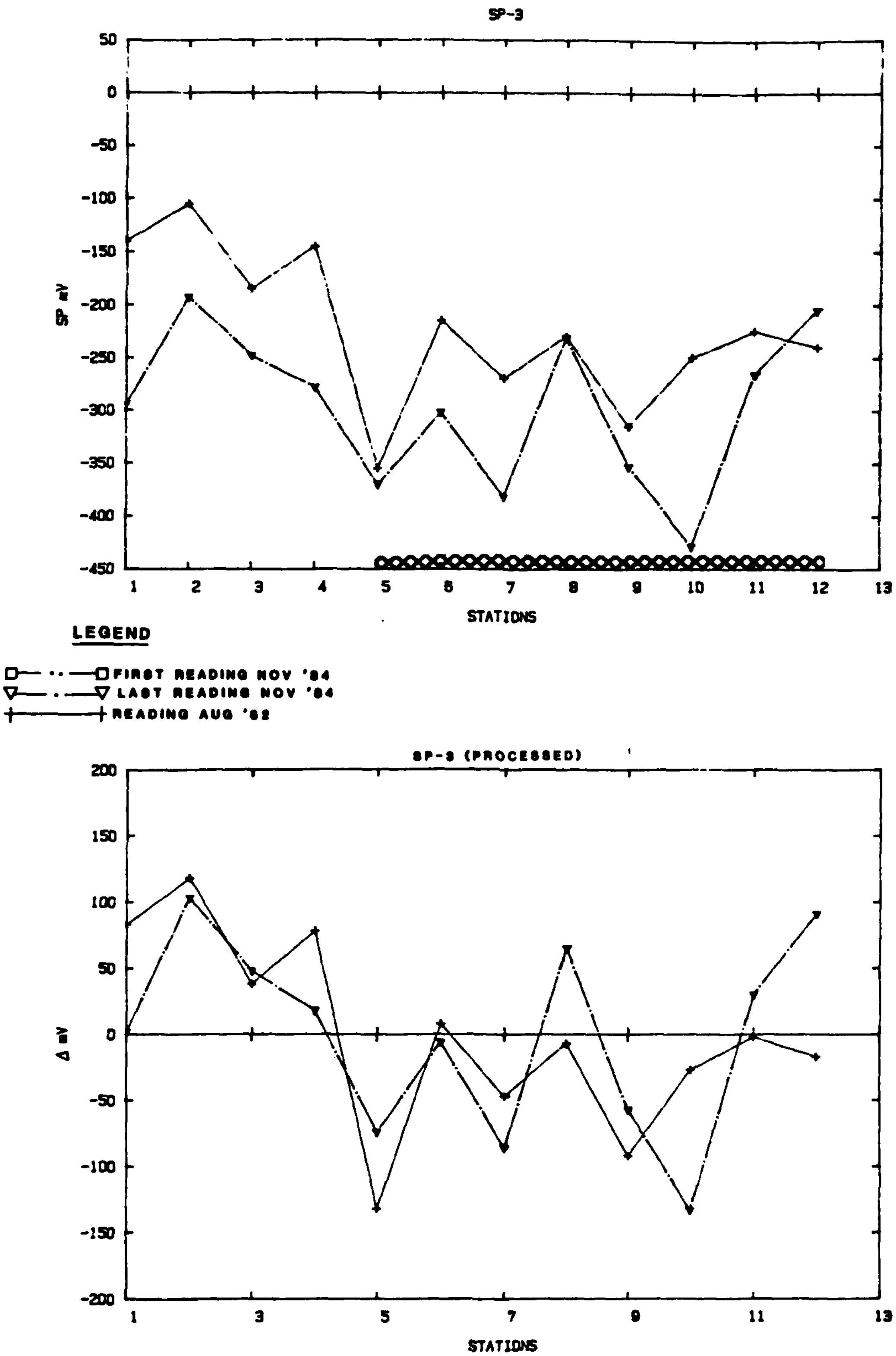

Figure 6. Self potential data for line SP-3

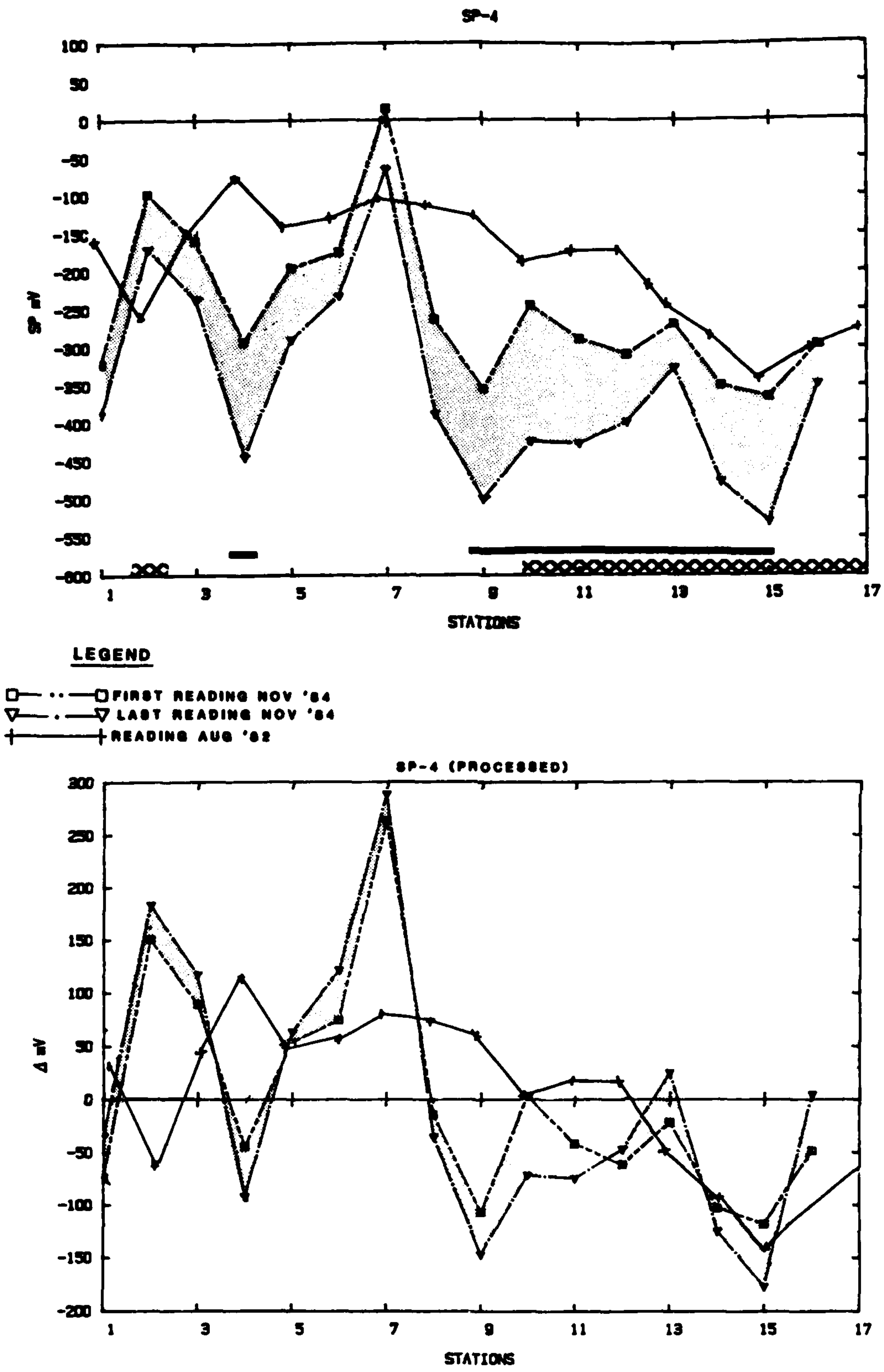

Figure 7. Self potential data for line SP-4

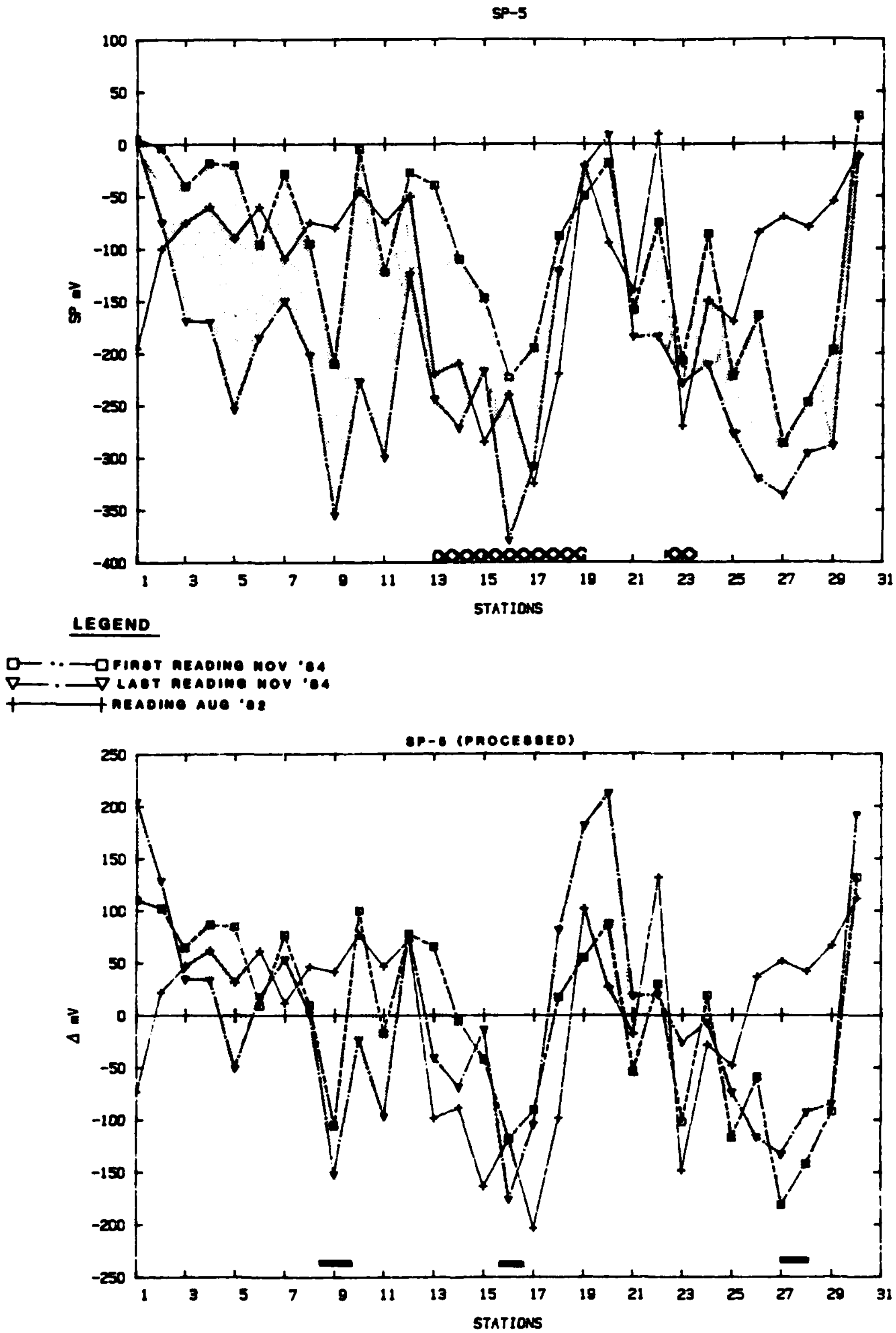

Figure 8. Self potential data for line SP-5

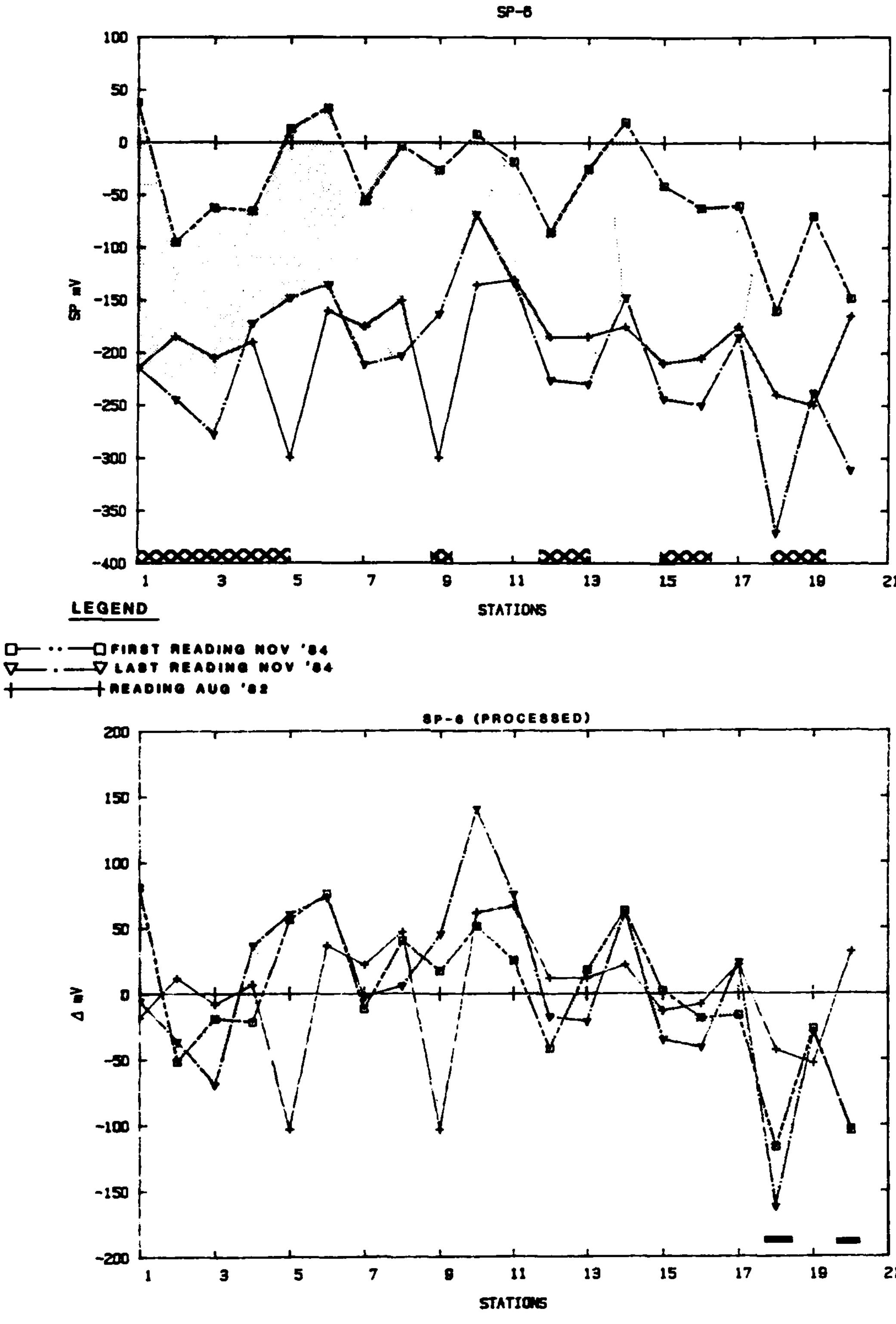

Figure 9. Self potential data for line SP-6

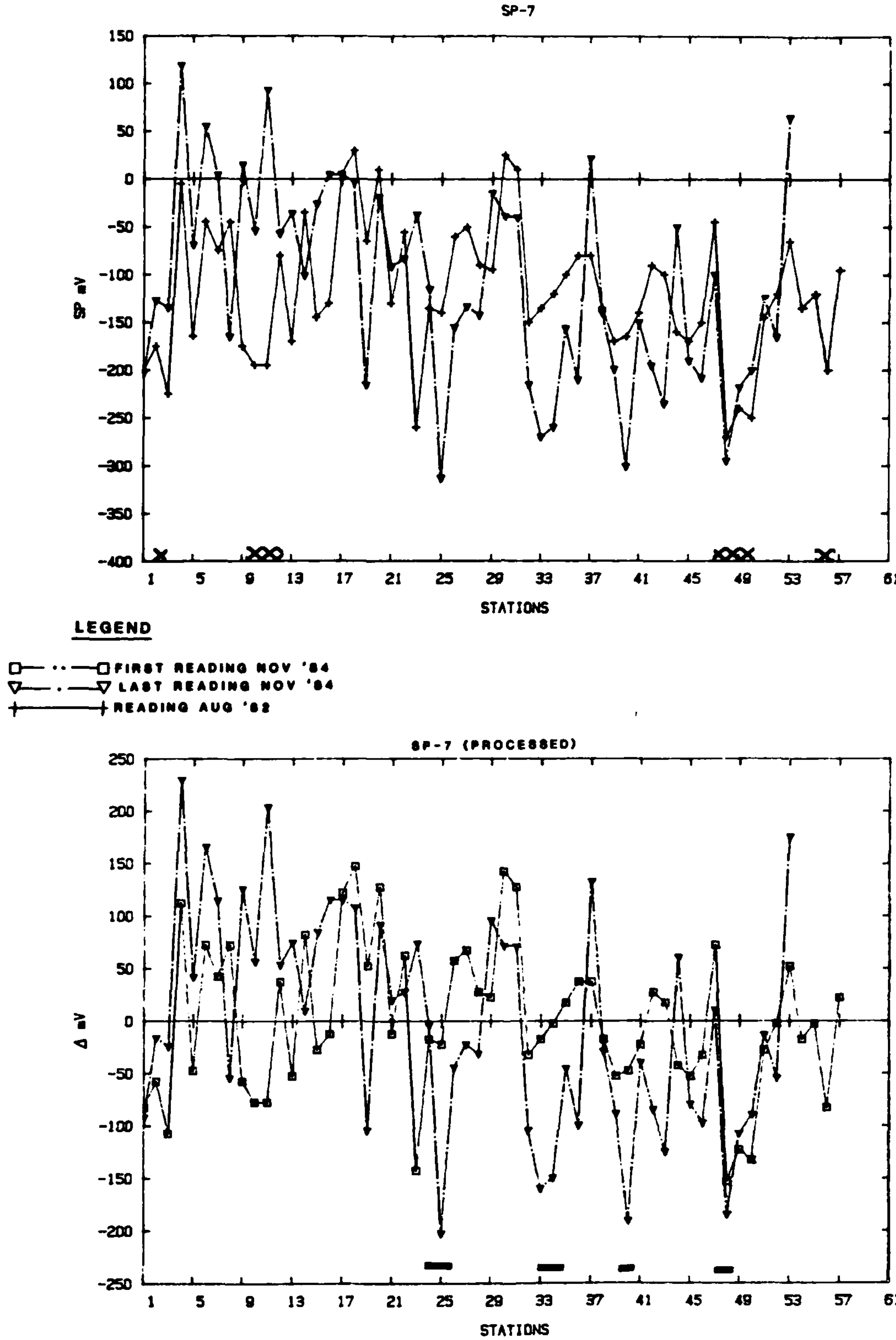

Figure 10. Self potential data for line SP-7

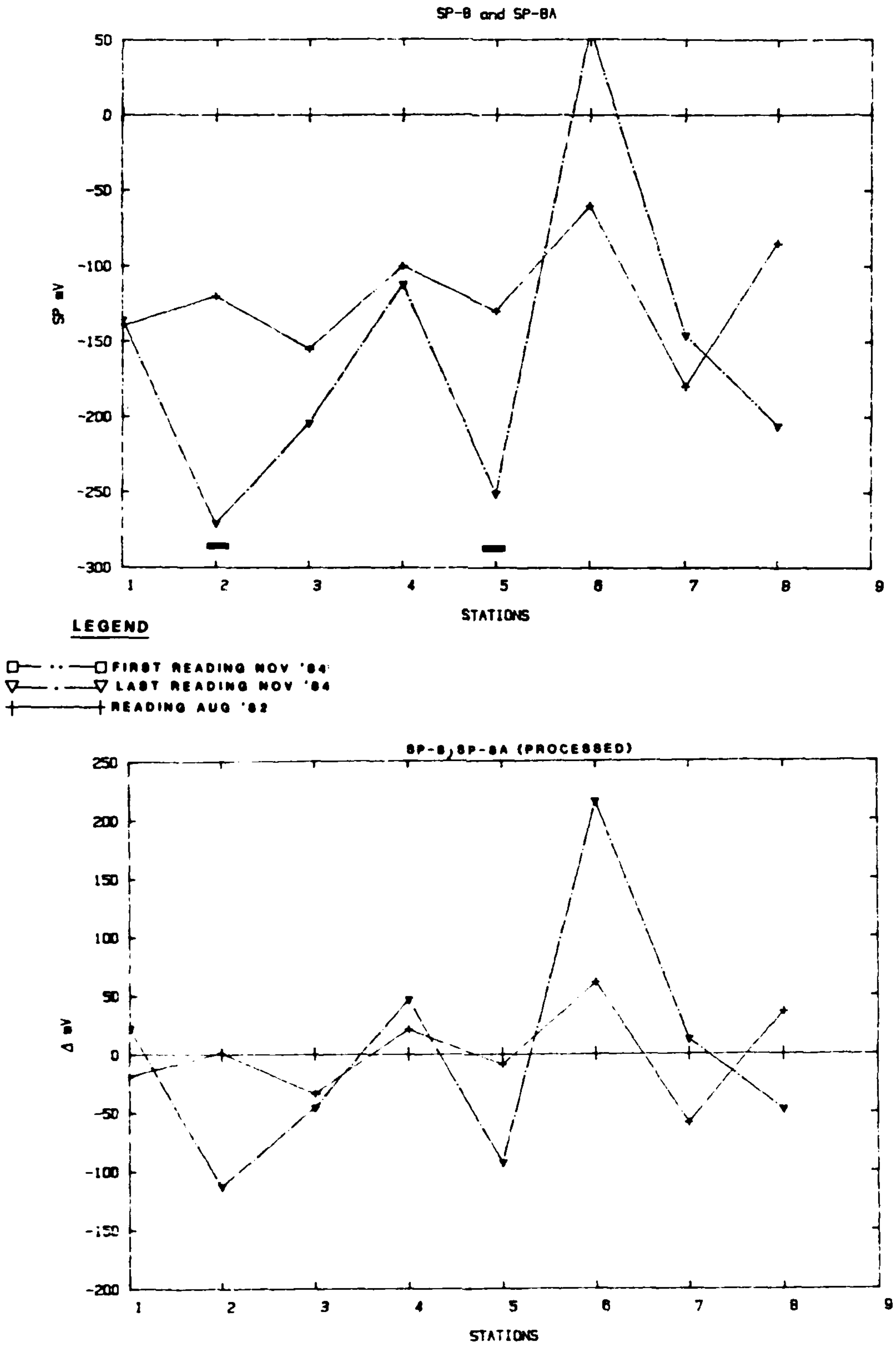

Figure 11. Self potential data for lines SP-8 and SP-8a

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