A mining research contract report
FEBRUARY 1982

Open file - Shannon & Wilson

REMOTE MONITORING OF A COAL WASTE IMPOUNDMENT IN WEST VIRGINIA

Contract H0282041
Shannon & Wilson, Inc.
Geotechnical Consultants

BUREAU OF MINES
UNITED STATES DEPARTMENT OF THE INTERIOR

REPORT DOCUMENTATION PAGE

1. REPORT NO.

2.

3. Recipient's Accession No.

4. Title and Subtitle

Remote Monitoring of a Coal Waste Impoundment in West Virginia

5. Report Date Prepared February 1982

6.

7. Author(s)

Gordon E. Green, David A. Roberts

8. Performing Organization Rept. No.

W-3466

9. Performing Organization Name and Address

Shannon & Wilson, Inc.
Geotechnical Consultants
1105 North 38th Street
Seattle, Washington 98103

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.

(C) HO282041

(G)

12. Sponsoring Organization Name and Address

United States Department of the Interior
Bureau of Mines
Washington, DC 20241

13. Type of Report & Period Covered

FINAL

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This report addresses remote monitoring of coal waste impoundments for stability. Existing automated geotechnical monitoring systems are described and reviewed along with details of instruments suitable for such systems. An impoundment in West Virginia which was in the construction stage was instrumented and monitored between July 1979 and May 1981. Sensors which measure surface and subsurface parameters including settlement, horizontal deflection, surface tilt, pore water pressure, seepage, pond level, and meteorological parameters were installed. Data from the 37 sensors were collected by on-site logger and transmitted by telephone to a central processing station in Seattle for recording and interpretation. Difficulties were encountered with telephone and powerline outages and malfunction of electronic units. Detailed descriptions of the design and performance of the system are provided along with evaluation and comparison with other systems. Recommendations for improving and expanding the capabilities of the monitoring system are given.

17. Document Analysis a. Descriptors

Coal Mining, Waste Disposal, Stability, West Virginia, Telemetering Data, Reservoir, Waste Disposal - Embankments, Earth Dams - Measuring Instruments

b. Identifiers/Open-Ended Terms

Coal Waste Impoundment, Waste Embankment Instrumentation, Remote Monitoring, Embankment Stability

c. COSATI Field/Group 8I

18. Availability Statement

Release unlimited

19. Security Class (This Report)

Unclassified

20. Security Class (This Page)

Unclassified

21. No. of Pages

173

22. Price

FOREWARD

This report was prepared by Shannon & Wilson, Inc., Geotechnical Consultants, Seattle, Washington, under USBM Research and Development Contract H0282041. The Contract was initiated under the Minerals, Health and Safety Technology Program. It was administered under the technical direction of the Bureau of Mines in Spokane with Barbee J. Scheibner acting as Technical Project Officer. William P. Battle and later Kent Charles were the Contract Administrators for the Bureau of Mines in Denver. This report is a summary of work performed between October 1978 and September 1981. This report was submitted by the authors in February 1982.

In addition to the listed authors, we wish to acknowledge the participation of P. Erik Mikkelsen, formerly with Shannon & Wilson, Inc., who preceeded Gordon E. Green as Project Technical Director during the equipment design and installation phase. The authors also acknowledge the assistance given by their colleagues and particularly Robert A. Robinson who wrote extensive portions of the Phase I report.

During the course of this project, assistance was solicited from both Federal agencies and private industry. Their cooperation and help is gratefully acknowledged. Special thanks are extended to the following people for their guidance and support in the site selection process: Robert J. Fujimoto, Chief of Mine Waste Branch, MSHA Denver Technical Support Center; Keluch Ke-Kang Wu, Chief of Mine Waste Branch, MSHA Pittsburg Technical Support Center; Harold Owens, MSHA District Specialist, Mount Hope, West Virginia; and other MSHA personnel. We would particularly like to thank the following personnel from the ARMCO No. 7 mine who gave us permission to use the Lower Big Branch impoundment site and assisted us during instrument installation and monitoring, including Clayton L. Condry, Jim Burton, Gary Halstead, Jim Jarrel, and Richard Weatherholt.

In our identification and assessment of instruments and data acquisition systems, we contacted many individuals who willingly shared information and experiences with us. These individuals have been identified in the References, and sincere thanks are expressed here. Many helpful discussions were held with Roger McVey, Electronics Specialist with the Bureau of Mines in Spokane. Finally, and most importantly, we extend our grateful appreciation to Barbee J. Scheibner, Technical Project Officer in Spokane, and Kent Charles, Contract Specialist in Denver. Their patience during the frustrations of delays, instrument failures, and telephone and power line failures is appreciated.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

TABLE OF CONTENTS (cont.)

Page

APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (cont.)

LIST OF ABBREVIATIONS AND SYMBOLS

ABS	Acrylonitrile-Butadiene Styrene
AC	Alternating Current
ADAS	Automatic Data Acquisition System
AWG	American Wire Gauge
A/D	Analog to Digital
ASCII	American Standard Code for Information Interchange
BCD	Binary Coded Decimal
CANMET	Canadian Center for Mineral and Energy Technology
CDCP	Convertible Data Collection Platform
CJB	Cable Junction Box
CJS	Cable Junction Station
CMP	Corrugated Metal Pipe
DC	Direct Current
DCP	Data Collection Platform
DL	Data Logger
EP	Electrical Piezometer
FCC	Federal Communication Commission
FS	Full Scale
FSK	Frequency Shift Keyed
GOES	Geostationary Operational Environmental Satellite
GND	Ground
II	In-Place Inclinometer
ID	Inside Diameter
in.	inch
IRAC	Interdepartmental Radio Advisory Committee
lbs	pounds
MPBX	Multiple-Position Borehole Extensometer
MSHA	Mine Safety and Health Administration
NESS	National Environmental Satellite Service
NOAA	National Oceanic and Atmospheric Administration
OD	Outside Diameter
PLS	Pond Level Sensor
psi	pounds per square inch

LIST OF ABBREVIATIONS AND SYMBOLS (cont.)

PWR	Power
PVC	Polyvinyl Chloride
RP	Resistance Piezometer
sec	second
SIG	Signal
SINCO	Slope Indicator Company
SRC	Spokane Research Center
SPT	Standard Penetration Test
TB	Terminal Block
TC	Thermocouple
TI	Traversing Probe Inclinometer
TM	Tilt Meter
TV	Test Voltage
TPO	Technical Project Officer
UHF	Ultra High Frequency
UMWA	United Mine Workers of America
VAC	Volts Alternating Current
VDC	Volts Direct Current
VHF	Very High Frequency
VWP	Vibrating Wire Piezometer
$^{\circ}$	Degree Angular
$^{\circ}C$	Degree Celsius
$^{\circ}F$	Degree Fahrenheit

SUMMARY

The primary parameters important in monitoring coal waste impoundment stability include:

- Pore-water pressure
- Horizontal deformation
- Vertical deformation
- Impounded water level
- Seepage through the embankment

These parameters have a significant influence on a stability evaluation of an existing impounding structure and in the assessment of the stability of other similarly constructed impoundments.

Following a thorough review and field visits to prospective coal waste impoundments, the Lower Big Branch impoundment of Armco Resource Co. at Montcoal, W. Virginia was chosen as the site for the proposed instrumentation system. Instruments and monitoring equipment were selected based on site-specific requirements and a detailed design report prepared for U.S. Bureau of Mines review and approval.

The remotely monitored automatic instrumentation system designed for this demonstration project included such instruments as electric piezometers, tiltmeters, in-place inclinometers, extensometers, seepage monitor, and pond level sensor. All instruments were connected by buried electrical cable to a central monitoring trailer located near to the embankment. Electronic equipment inside the trailer supplied power to the sensors, conditioned the sensor output, measured the electrical signals and recorded the data. Data was recorded automatically at the site on paper tape and on request at Shannon & Wilson's Seattle office via the telephone system.

Monitoring was performed intermittently during the period July 1979 to May 1981. Breakdown of equipment and loss of the electrical power line prevented continuous, uninterrupted monitoring. Most equipment failures were associated with the signal conditioning equipment.

Other automatic data acquisition systems for geotechnical instrumentation are discussed and compared to the system designed for this project. An approximate cost analysis for this system indicates that an automatic system is justified if the impoundment is monitored three times per week for an eight-year period. A manual system would be more economical for less frequent monitoring.

1.0 INTRODUCTION

1.1 Project Objectives

Increased governmental regulations, since the Buffalo Creek failure in 1972, have prompted the need for a rapid and practical means of continuously assessing the performance of coal waste impoundment structures. Existing firsthand inspection techniques do provide various levels of qualitative assessment of impoundment structure safety. However, the rapidly increasing number of structures precludes assignment of governmental agency personnel to the continuous inspection of individual structures. There is thus a need for an integrated, remotely monitored instrumentation system capable of quantitatively monitoring stability and seepage parameters for impoundment structures with provisions for access to and assessment of current instrumentation data. A central data processing facility for monitoring instrumentation in several different embankments provides for further cost and personnel efficiencies. However, these goals may be difficult to achieve within the present state-of-the-art of the geotechnical instrumentation industry.

The Mine Safety and Health Administration (MSHA) is currently applying remote sensing technology (satellite imagery) to detect roof falls and pit wall failures, and interest has been generated to apply remote sensing to other observational tasks performed by MSHA. MSHA is responsible for the review of all plans for active impoundment facilities, periodic inspection in the field, and assessment of the safety of such facilities. Surveillance of the various impoundment structures by automated remote means could give a more quantitive evaluation of stability, serve as an early warning system and potentially reduce man-hours in the field. This research project is aimed in the direction of these goals.

Specifically, the purpose of this project was to design, install, and field test an Automated Data Acquisition System (ADAS) at an existing coal waste impoundment. Information obtained through this study would then be utilized in assessing the costs of such a system, as well as the effectiveness of the designed system.

1.2 General Scope of Work

This project is limited to the development and demonstration of an instrumentation system which will remotely monitor horizontal and vertical movements, pore-water pressure changes, pond water levels, seepage, and meteorological parameters for a coal waste impounding structure. The work has been conducted in two phases in general accordance with our proposal and U.S. Bureau of Mines Contract No. H0282041, Article I - Statement of Work dated September 30, 1978.

To provide a well integrated instrumentation and remote automatic data acquisition system suited to the mine environment, this study evaluates the various monitoring system components, the various physical parameters which are diagnostic of embankment stability and are amenable to remote monitoring, and the site conditions which might control the selection and implementation of instrumentation system components. Our basic approach to this investigation includes the following scope of work:

Phase I

- An extensive review and evaluation of available instrumentation and remote monitoring systems and techniques which may be applicable to waste embankment monitoring.
- Evaluation of available climatic, physiographic, engineering, mining and governmental data to select candidate study mines.
- Visits to candidate mines to evaluate site-specific conditions with respect to access, instrumentation installation, embankment construction, mine owner assistance, available data acquisition, and reduction facilities, etc.
- Detailed design of a complete, remotely monitored instrumentation system for a selected coal waste impoundment site.

Phase II

- Instrumentation procurement.
- Installation and field evaluation of the selected instrumentation system.
- Engineering studies to evaluate system performance, capital and operations costs, and comparison with other known remote monitoring instrumentation systems.
- Recommendations for specific instrumentation and monitoring equipment development requirements.

1.3 Report Format

This final report represents a combination of the information obtained as a part of Phase I and the actual field work and designed system evaluation. Section 2 presents the initial site selection process and a brief description of the chosen field site. Section 3 contains a description of geotechnical parameters and measurement techniques appropriate for an impoundment structure. A general bibliography of geotechnical instrumentation has been included in Appendix A to provide additional information for readers unfamiliar with the subject. Section 3 also discusses various aspects of automatic data acquisition and remote monitoring.

In Section 4 the system designed and installed at the selected site is discussed in detail including installation procedures and the monitoring program. Data from the instruments is evaluated and interpreted and the overall system performance is discussed in Section 5. Section 6 attempts to relate the system established for this project with other examples of geotechnical remote monitoring and describes situations where other systems would be more appropriate. System costs are discussed and placed in perspective relative to the benefits obtained.

Recommendations and conclusions are presented in the final section and the appendices contain specific information and data which are important to a detailed knowledge of the designed system, but which are not critical to understanding the project.

2.0 SITE SELECTION

2.1 Selection Guidelines

Selection of the candidate sites for the proposed coal waste impoundment monitoring system involved interviewing MSHA engineers at the Denver and Pittsburgh Technical Support Centers and searching the MSHA files on operating impoundments. At first, the files were searched for 'hazardous' impoundments, but the regulations which were promulgated by MSHA (formerly MESA) after the Buffalo Creek disaster have forced the coal industry to turn waste dumps into engineered structures. Since particularly troublesome and challenging sites were not immediately apparent, the following factors were eventually considered in selecting the project site.

- Location in a populated area with high precipitation rates.
- Some certainty of measuring parameter changes such as deformation, water pressure, fluid levels.
- Height of structure in the range of 100 to 200 feet.
- Cooperation of mine owner and permission to use the waste impoundment.
- Electrical power and telephone available close to site.

These particular factors were selected on the basis of the contract requirements, cost estimates made in the proposal and to best demonstrate the full capabilities of a remote monitoring system.

2.2 Impoundments Visited During Site Selection

Following conversations with several MSHA and Bureau of Mines personnel, five sites were short-listed for either a visit or further study by contacting engineers at the site. The impoundments reviewed during site selection are described below.

Moss No. 3, Dante, Virginia

The site is about two hours drive from Tri-Cities Airport, Tennessee and belongs to the Clinchfield Coal Company. The company has two large impoundment facilities in the area, Moss No. 1 and Moss No. 3. MSHA Engineer, Ed Beck from Technical Support in Denver, was involved in design review and told the company we were interested in the site. We were invited by Mr. John Curran and Mr. Mike Holbrook, geotechnical engineers with the Clinchfield Coal Company, to use the site for our project.

We reviewed Moss No. 1 site with Mr. Holbrook and found it not to be particularly well suited. Moss No. 3, however, had a better potential. Moss No. 3 was the largest embankment considered for this study. The height in 1978 was about 330 feet and the width of the active filling area was about 1000 feet. The crest was to have been raised about 50 feet over the next few years and the downstream slope flattened and benched using coarse refuse. The planned construction formulated with the assistance of L. Robert Kimball, Consulting Engineers, would result in reported increase in embankment stability. The tailings pond level was controlled by an interior (secondary) dike 40 feet lower than the 300-foot wide crest.

The disadvantages of this site area were: low potential for measuring deformations, extra expense for deeper instrumentation boreholes and extra hardware cost. Access was only fair; the muddy, rutted roads would require 4-wheel drive at all times. The distance to power and telephone was about 2000 feet. Filling would occur over the top of the sensor locations, so instruments would not be accessible or recoverable in the future.

Tug Fork, Jenkinjones, West Virginia

This site was the most remote of the sites visited, but the roads were fairly well maintained. This was the second site recommended by Mr. Owens in District 4. The site is three to four hours driving time south of Charleston, West Virginia. The mine is operated by Consolidation Coal Company. We met the mine superintendent, Mr. Jack Moorefield, and looked over the impoundment. The plans developed by Bowser-Morner Testing Laboratories, Inc. showed a six-stage sequence of construction using the upstream construction method. Fully developed, the embankment will be close to 300 feet high. At the time of the visit the embankment was in its first stage, approximately 100 feet high. The next stage would be interesting to monitor, but construction would not start until late 1979. Because of the uncertain filling schedule, the remoteness of the site and the lack of power and telephone close to the site, this candidate was considered less suitable than others.

Joe Branch, Itmann, West Virginia

This mine also belongs to the Consolidation Coal Company and is located about one hour drive southwest of Beckley. The embankment is old, but is still active. D'Appolonia Consulting Engineers, Inc. has developed plans for upstream staged filling to raise the impoundment level about 130 feet over the next decade or two. Much of the existing 270-foot high embankment is on fine refuse. Burning refuse was noted on the downstream slope on 1975 plans. The fine refuse under the coarse refuse embankment is 60 to 70 feet thick.

We consider this site to be the second best candidate, although we did not have an opportunity to visit the site itself. The information on this site was obtained from District 4 and was the third site recommended by Harold Owens. When we were in the area, we contacted Mr. Claude D. Morgan, Supervisor of Design and Construction for Consolidation, but could only arrange the visit to Tug Fork. Mr. Morgan was interested in our instrumentation project, but could not arrange any visit to Itmann during that particular week.

Laurel Mine, Near Johnstown, Pennsylvania

This mine is another Consolidation Coal Company operation about two hours drive east of Pittsburgh. One of the mine engineers, Mr. Jim Eyth, showed us around the facility during our visit. D'Appolonia Consulting Engineers, Inc. has designed a new six-staged embankment utilizing the upstream construction method. Ultimately, the embankment will be about 200 feet high after about 15 years. By June 1979, the embankment will probably be at the end of Stage II, a 40-foot high embankment impounding a small amount of fine refuse slurry. The Stage III filling would commence some time afterwards, adding another 20 feet to the embankment. The existing soil overburden is about 75 feet thick. Should we have decided to install instruments to rock from Stage II bench, the depth to rock would be 115 feet deep. The length of the embankment along the crest is on the order of 700 feet and the embankment is located in fairly open, gently sloping terrain.

If this embankment had been at a more advanced stage and height, it would have been a good candidate. At this stage, and with the filling schedule somewhat uncertain, we could not expect much to happen in terms of changing water levels and deformation due to consolidation. Also, the potential hazard is reduced at this stage since very little slurry and only a limited amount of water can be impounded. We did not consider this a suitable candidate site.

Lower Big Branch, Montcoal, West Virginia

This site was eventually selected as the site for the instrumentation system and is described in Section 2.3.

In summary, the candidate mines, in our assessment, rank in suitability, as follows:

Prime Candidate - Lower Big Branch, Montcoal, WV
2nd choice - Joe Branch, Itmann, WV
3rd choice - Moss No. 3, Dante, VA
4th choice - Tug Fork, Jenkinjones, WV
5th choice - Laurel Mine, Johnstown, PA

2.3 Recommended Site

The coal waste impoundment chosen for detailed study and design of a remotely monitored, automatic data acquisition system was the Lower Big Branch Impoundment at Montcoal, West Virginia. This impoundment is operated by ARMCO Material Resources, and is used to dispose of the fine coal refuse and part of the coarse coal refuse from the coal preparation plant at Montcoal. The remaining coarse coal refuse is disposed of at a nearby embankment (River Fork).

Montcoal is about 1.5 hours drive from Charleston, West Virginia along Highway 3 (Figure 2.1). The impoundment is located in a west-trending valley approximately one mile downstream from the preparation plant. The site is relatively steep with heavily wooded hillsides. Lower Big Branch is a small tributary of Marsh Fork Creek which, in turn, flows into the Coal River. The disposal facility consists of a cross-valley coarse coal refuse embankment which impounds the fine coal refuse slurry pumped from the preparation plant. Figure 2.2 shows the impoundment and topography of the surrounding area. The site has been used for coal refuse disposal since about 1958, but most of the major construction has occurred during the 1970's. During this period the height of the embankment has been raised and recontoured several times, and in 1978 the most recent phase of embankment raising was begun. D'Appolonia Consulting Engineers, Inc. has been involved since 1972 in this development of the site. A major field investigation was initiated in 1974 which consisted of test pits, borings, piezometer installation, and laboratory tests on samples of refuse. We have utilized these reports and logs in our instrumentation design.

Geology of the area consists of interbedded layers of sandstone, shale and coal, capped with a thin layer of residual soil. The total watershed for this impoundment is approximately 505 acres with approximately 5 acres of impoundment. There are

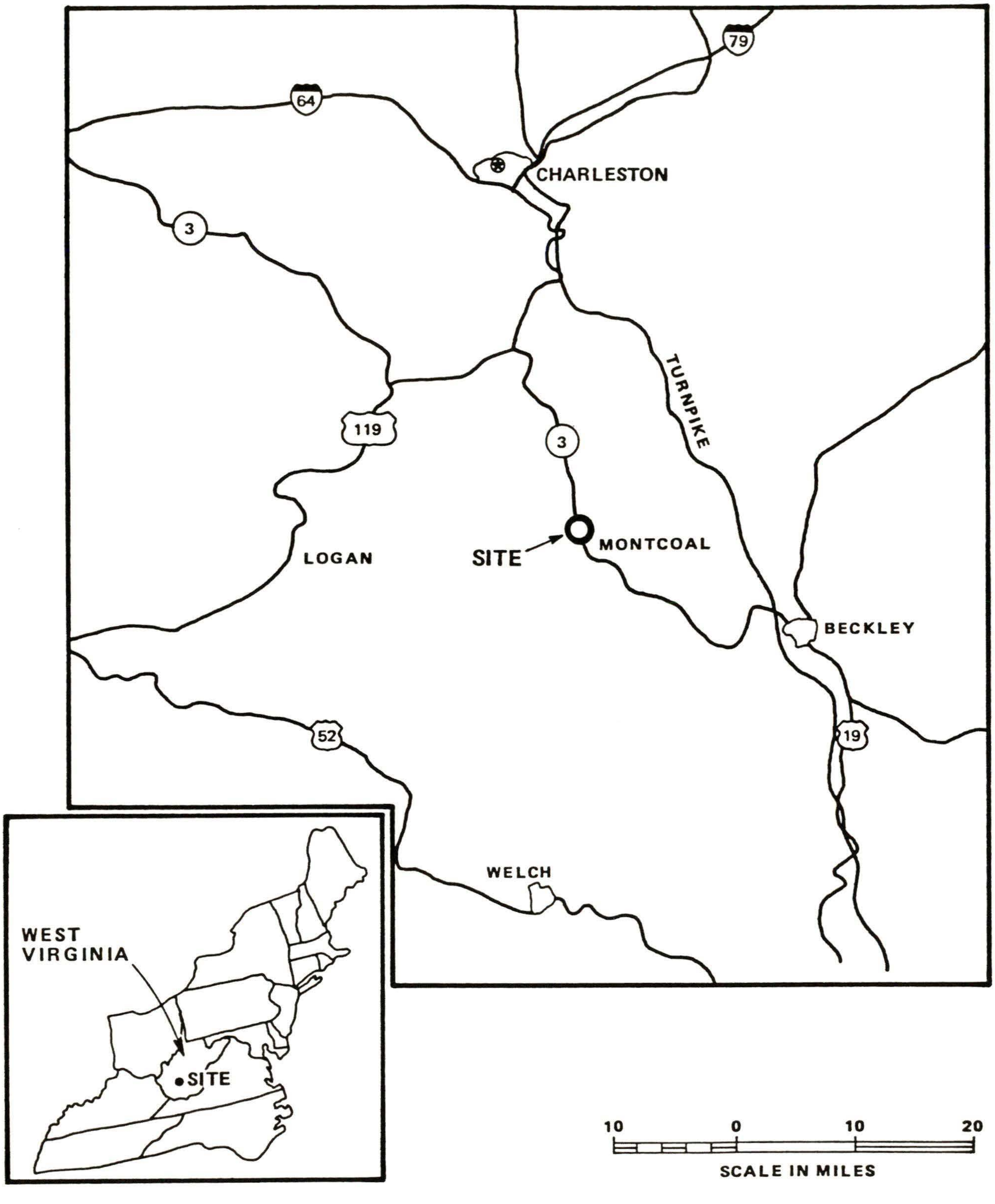
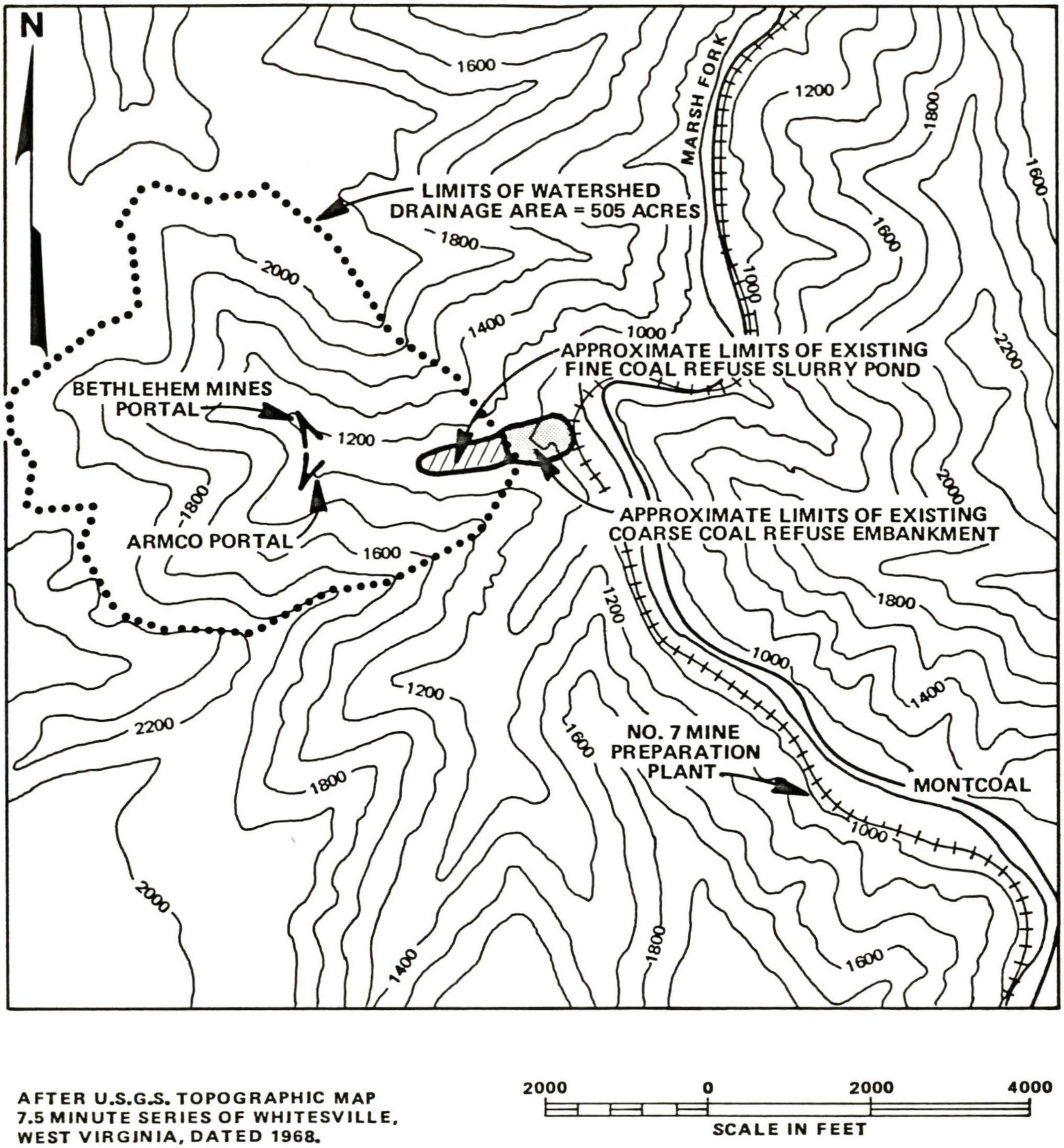


FIG. 2.1 Vicinity Map of ARMCO Lower Big Branch Site; Montcoal, West Virginia



AFTER U.S.G.S. TOPOGRAPHIC MAP
7.5 MINUTE SERIES OF WHITESVILLE,
WEST VIRGINIA, DATED 1968.

FIG. 2.2 Site Map of ARMCO Lower Big Branch Site; Montcoal, West Virginia several notable features which have controlled the design of the impoundment:

- A cemetary is located along the north side of the valley.
- A gas well and gas line are located along the north side of the valley. The gas line has been rerouted for this phase of impoundment construction.
- Two active mine portals are situated upstream from the embankment at approximately elevation 1180 feet.

Crest elevation at the beginning of the last expansion phase was 1120 feet. The refuse was then about 190 feet thick at the center of the valley below this crest. Embankment construction is by the upstream method, with coarse coal refuse placed on top of fine refuse and then compacted. During the present phase, the embankment will be raised in two stages to a final elevation of 1175 feet. The natural stream will be diverted through the impoundment via a corrugated metal pipe and an emergency spillway will be constructed.

Our first visit to the site was on December 11, 1978, when the Technical Project Director was reviewing candidate sites. We met with the Chief Engineer, Mr. Clayton L. Condry, the Manager of Engineering Services, Mr. Richard Weatherholt, and the Construction Supervisor, Mr. Jim Burton, and discussed the use of the impoundment as a site for the monitoring system and reviewed the history of the impoundment. The mine personnel were very cooperative and had no objection to the use of their facility for this project, unless time and expense need be expended by the mine.

A second visit to the site was made between February 7 and 13, 1979, for the purpose of obtaining information on the impoundment construction along with copies of boring logs and test pits and photographs of the impoundment. During the visit, discussions were held with prospective subcontractors for the drilling, electrical power, and field construction work, along with the telephone company and retail businesses for the purpose of estimating project costs. Quality of transmission through local telephone lines was tested during the visit and samples of pond water were obtained for testing.

Access to the crest is good via a well maintained haul road across the downstream embankment slope. Electrical power and telephone service is available within 1000 to 2000 feet of the embankment crest. The next stage of embankment filling will be extended over fine refuse and we could expect to detect consolidation of these materials. The timing of the present phase of construction made this site the most promising in terms of anticipated movements and changes in parameters associated with construction.

After reviewing all the potential sites and discussing their relative merits with the Technical Project Officer, this site was chosen because it met all of our requirements as outlined in Section 2.1. The site is easily accessible, with nearby electrical power and telephone. Following raising of the embankment crest, we have a reasonable prospect of measuring deformations and changes in fluid levels and water pressure. The required borings for installing instruments would be a maximum of 180 feet deep, with shallower boreholes near the sides of the valley. Previous available borings and laboratory tests on the embankment material should provide a good base for choosing the instrument locations and for analysis of the data obtained during monitoring.

3.0 GENERAL INSTRUMENTATION REQUIREMENTS AND INSTRUMENT AVAILABILITY

3.1 Geotechnical Parameters

3.1.1 General

There are several geotechnical parameters which are important in assessing and monitoring the stability of a coal waste impoundment. Many of these parameters are common to any water impounding structure such as a concrete dam, earth dam, levee, sedimentation pond, or waste storage pond. Knowledge of all of the geotechnical parameters discussed below are not necessary, and useful stability analyses can be performed with only a select number of these parameters being known. Some of these parameters may change during and after construction of the impoundment, while others remain unchanged.

The parameters can be roughly placed in three categories: impoundment geometry, material properties, and external influences. Geometric parameters include height, slope angles, location of various layers of different materials, and topography. Material properties include strength parameters (cohesion and angle of internal friction), density, permeability, grain-size, and porosity for each type of material within the impoundment. External influences include external forces such as water pressures or surcharges and the associated stress changes and deformations within the embankment.

The geometric parameters are generally fixed at the design stage and as long as construction follows the engineering drawings, these variables rarely change. Impoundment material properties are generally determined during design or evaluation by an extensive field exploration program accompanied by a lab program. Some of the properties may vary during actual construction, such as maximum density and grain-size. However, these changes are generally controlled by a combination of assuming the worst conditions and careful monitoring of construction. Material properties may also be altered during the life of the impoundment by chemical and mechanical decomposition, secondary cementation, piping of fine material and increases in strength due to consolidation. Monitoring of these types of changes are very difficult to perform by traditional manual methods, and even more difficult remotely or automatically. Tests to measure these changes generally require excavation, sampling, and elaborate testing for each data point and are impractical for day to day remote monitoring.

The third category of parameters, those associated with external influences and associated stress changes and deformations within the impoundment, are the ones most likely to change and are those which have been traditionally monitored. Some of these parameters, when combined with good engineering judgment, can be used to estimate changes in other parameters. The major parameters within this group are: vertical and horizontal deformations; vertical and horizontal stresses; pore-water pressures; surface tilt; upstream pond water level; seepage quantities through the embankment; and meteorological parameters. Meteorological parameters are a secondary group which indicate indirect influences on either the impoundment or the geotechnical instruments. The various parameters will be discussed in detail in the following sections.

3.1.2 Vertical Deformations

Generally, embankment deformations associated with instability include some component of vertical deformation. This deformation may be the result of settlement or piping or a component of slide movements. Vertical and horizontal movements at the surface can be monitored periodically with standard surveying techniques, but movements at depth require more sophisticated methods. Exact location of the source of vertical deformation can provide needed information to understand the cause of the deformation and its influence on impoundment stability.

3.1.3 Horizontal Deformations

Horizontal deformations are used as an indicator of the potential zones or planes of weakness. Mass movements associated with instability of embankments are often preceded by small but measurable deformations (strains) reflecting incipient failure. Generally, these deformations contain some component of lateral translation. There are some stability analysis techniques which can utilize measured strains to estimate the overall embankment stability, although their current reliability and usage is limited.

3.1.4 Pore-Water Pressures

Pore-water pressure is a component of the stresses within the embankment, but is of such great importance in stability analysis, especially for an impoundment, that it deserves special mention. Pore-water pressure is an independent variable which can change rapidly and dramatically. Pore-water pressure probably represents the most important variable in useful stability analyses available today. Water in the embankment is important, in that although it increases the unit weight of the saturated material it also provides an internal fluid pressure within the interstices of the soil. This pore-water pressure tends to reduce the effective stress between the soil grains and, hence, the frictional resistance to shear of the embankment materials. The pore-water influence is often expressed in the form of a "phreatic surface". The phreatic surface represents the upper boundary of water flowing through the embankment. The pore-water pressure is zero (atmospheric) at this surface and increases with depth at a varying rate, depending on the flow regime. If the phreatic surface intersects the downslope face of the dam, a seep or spring occurs. The concept of a simple single phreatic surface within the embankment is valid in only certain cases. In particular, in a zoned fill waste impoundment embankment where a variety of materials are placed in staggered layers, a complex pore-water pressure regime may exist.

3.1.5 Total Stresses

The stress regime within an embankment can be conveniently defined in terms of total stresses, effective stresses, and pore-water pressures, where total stress = effective stress + pore-water pressure. The total stress tends to remain constant unless additional fill is placed to raise the embankment or the upstream pond, or the fines level is raised. Pore-water pressures can vary due to seepage and leakage so that the effective stresses which control shear strength and stability also change. Unfortunately, direct measurement of total stress is technically difficult, expensive, and time-consuming, and in many instances, the results are questionable. In addition, very few instruments are suitable for remote monitoring over a long period of time. Other parameters such as external forces, deformations and body forces, are more often used by the engineer to estimate the total stresses within an embankment.

3.2 Instrumentation Available to Measure Parameters

3.2.1 General

Many types and models of instruments are available to measure the geotechnical parameters discussed in the previous section. Since the purpose here was to remotely measure geotechnical parameters, we have only considered those instruments which could conveniently be included in a remote monitoring system. Thus, there are a number of high quality instruments available to measure these parameters which we have not considered. In the design of the instrumentation system for Lower Big Branch, the identification of suitable instruments was limited to North American manufacturers. Numerous reliable European manufacturers exist, but their prices are generally 50 to 100 percent higher than North American manufacturers. In addition, procurement and repair are more difficult, and obtaining specifications and performance information of European instruments is more difficult.

Information on the attributes of various instruments was obtained from manufacturers' data sheets, discussions with manufacturers, and our past job files and personal experience. Performance information was obtained from our field experience and the experience of individuals from government agencies, private industry, and other geotechnical consulting firms. In general, we received excellent cooperation from government personnel, manufacturers and other users in collecting the information and making assessments. Since all the instruments were to be remotely measured, the information from the instruments had to be transmitted by some means to the central on-site collecting station. Many ways exist to transmit information from sensors, such as optical, hydraulic, pneumatic, electrical and mechanical. For the distances involved and sensor options available, electrical transmission was determined to be most effective. Eventually all the information must be converted to one format to facilitate collection and processing. Electrical instruments provide both the most flexible transmission system and the largest number of available proven sensors for the various parameters. Thus, we have concentrated our study on instruments which employ electrical sensors. Although almost any instrument can be converted to produce an electrical output if sufficient time and money are expended, we have generally discarded this method except where the non-electric sensor has a very specific advantage.

3.2.2 Vertical Deformations

Surface settlement can be measured periodically with standard surveying methods, whereas remote monitoring requires permanent connection to a nearby reference point. In many cases, the nearest reference point is bedrock at depth below the embankment. Thus, a borehole extensometer becomes the most convenient method to monitor both surface and subsurface vertical deformations. Since drilling the borehole is usually the most expensive part of the extensometer system, multiple-anchor extensometers are very suitable. Components for a borehole extensometer include a subsurface anchorage system, a sleeve-protected rod or wire, and a reference head containing electrical displacement sensors. The rods or wires are connected to subsurface anchors and extend to the ground surface to measure deformations between the anchor and the reference head. Borehole extensometers are usually of two types using either wires or rods to transmit anchor movements to the reference head. Wire extensometers have generally been found to be more prone to errors than rods due to the need to keep the wires tensioned, which may result in long-term creep deformations. In addition, it is difficult to prevent tangling of the wires during installation, which results in frictional drag on the wires. Consequently, wire-type extensometers have been discarded from further consideration and only rod-type systems are evaluated in detail.

Four rod extensometer systems have been evaluated and are listed on Table 3.1. Specifications are given on Table 3.2. One of these systems uses a new type of sensor for monitoring displacements; the other three systems use conventional linear potentiometers to monitor movements.

A new extensometer system was recently developed, marketed by Irad Gage Company*, of New Hampshire as part of a Bureau of Mines research project (Hawkes, 1978). This system uses the principle of monitoring the return interval for sonic pulses launched in a magneto-strictive wire placed in a magnetic field. The magneto-strictive wire and sonic pulse generator are enclosed in a portable 4 to 10-foot long rod-like probe which may be permanently nested amongst the anchor rods. A rod magnet is fastened to the upper end of each anchor rod which affects the return rate of the sonic pulses generated in the adjacent probe. This system of measurement has an overall sensitivity of 0.005 inch which should be adequate for monitoring the magnitude of vertical deformations in a waste impoundment embankment. Current (1981) opinion indicates that the probe head is not fully waterproofed and a number of failures have occurred. For some applications we consider that this system could be more cost-effective than other systems using linear potentiometers. However, automatic data acquisition from the Irad Gage magneto-strictive system poses several costly problems. Since all of the anchor rods in a borehole are monitored by a single sensing probe, the probe requires an electrical switching device to differentiate between the individual anchor rods. Each borehole system requires its own switching device at an additional cost. Furthermore, the data are in a digital format and a data logger must be capable of accepting digital data or the digital signal must be converted to an analog voltage. Irad Gage does offer an interface between the sonic probe and their data logger, but we have been unable to ascertain the effectiveness of this system. Commercial data loggers are primarily designed for analog data and, consequently, special, costly modifications would be required to add several channels of digital data.

Three borehole extensometers employing linear potentiometer sensors are listed on Table 3.1, and are conceptually very similar, differing only in details of the various components used. Sensors other than linear potentiometers could be used with the extensometers, such as linear variable differential transformers (LVDT's), but the additional accuracy does not generally justify the additional cost. These other sensors have their own technical disadvantages. An example of this type of extensometer (Slope Indicator model) is shown on Figure 3.1. The extensometer produced by Terra Technology of Redmond, Washington is constructed so that displacements may be monitored simultaneously with linear potentiometers and a portable depth micrometer. To monitor the other two systems with a portable depth micrometer requires that the linear potentiometers be removed, consequently interrupting the electrical reading and requiring resetting the potentiometers. Users have reported a very high percentage of failures for the Terra Technology instrument

---

*Reference to specific manufacturers does not imply endorsement by the Bureau of Mines.

TABLE 3.1

Description of Rod Extensometers for Measuring Vertical Deformation

Instrument Type	Instrument Model	Instrument Characteristics
Magneto-strictive Sonic Probe	Irad Gage Co. Sonic Probe Extensometer	A 30 to 60-inch long electronically monitored magneto-strictive sonic probe installed in a borehole monitors the position of magnets on rods anchored at various depths along the borehole. System used grouted rebar anchors for soil or expansion anchors for rock. Rods encased in plastic tubes which may be oil-filled to reduce friction. Rod can be disconnected from anchor to check freedom of movement. Maximum practical anchor rod length 300 feet. Typically from 1 to 5 rods.
Linear Potentiometer	Slope Indicator Co. Linear Potentiometer Extensometer	Linear potentiometers monitor position of 1 to 5 anchored stainless steel rods. Rods operate inside plastic sleeves. Rods anchored with hydraulically expandable pronged anchor or grouted rebar anchors. Plastic sleeves may be filled with oil to reduce friction. Rod detachable from anchor to check freedom of movement. Maximum practical rod length of 300 feet. Typically from 1 to 5 rods.
	Solinst, Canada Ltd. Linear Potentiometer Extensometer	Same as above, but with either expansion shell anchor for rock or grouted rebar anchor for soil.
	Terra Technology Linear Potentiometer Extensometer	Same as above, but without threaded insert for rod extension.

TABLE 3.2

Specifications of Rod Extensometers for Measuring Vertical Deformation

	Irad Gage Co. Sonic Probe Extensometer	Slope Indicator Co. Linear Potentiometer Extensometer
Model Number	4500	51703
Range	0 to 10 feet, 35°F. to 150°F. No restriction on cable length.	4-inch displacement which may be mechanically extended. Cable lengths up to 1500 feet.
Output Specification	Sensitivity 0.005 inch. Thermal Coef. .007% of FS/$^{\circ}$F. Nonlinearity 0.05% FS.	Sensitivity 0.001 inch. Nonlinearity 0.1% FS.
Power Requirements	±15 VDC	4 to 12 VDC. Precision input.
Output	0-10 VDC	0-12 VDC depending on input.
Wires per Sensor	5	3 to 5
Calibration and Maintenance	Sonic sensor may be removed and position of rods measured with a depth gage. Sonic sensor has reference magnet for in-place calibration.	Potentiometers may be removed for calibration or repair. Rods may be measured mechanically with depth gage.
Reliability and Durability	Recently developed system with some field testing but no long-term experience. Some problems with waterproofing.	Excellent long-term and under submerged conditions.
Ease/Cost of Installation	Installation in 3-inch boreholes with grouting.	Installation in 3-inch boreholes with grouting.
Ease/Cost of Monitoring	Direct monitoring of displacement with linear conversion requires separate switching system with multiple anchors at each instrument location. Output in BCD requires additional conditioning.	Direct linear conversion of voltage displacement.
Availability	6 to 8 weeks	6 to 8 weeks

TABLE 3.2 (cont.)

Specifications of Rod Extensometers for Measuring Vertical Deformation

	Solinst, Canada Ltd. Linear Potentiometer Extensometer	Terra Technology Corp. Linear Potentiometer Extensometer
Model Number		
Range	4-inch displacement which may be extended mechanically up to 20 inches. Cable lengths up to 1500 feet.	4-inch displacement. Cable lengths up to 1500 feet.
Output Specification	Sensitivity 0.001 inch. Non-linearity 0.1% FS.	Sensitivity 0.001 inch. Non-linearity 0.1% FS.
Power Requirements	4 to 12 VDC. Precision input.	4 to 12 VDC. Precision input.
Output	0-12 VDC, depending on input.	0-12 VDC, depending on input.
Wires per Sensor	3 to 5	3 to 5
Calibration and Maintenance	Potentiometers may be removed for calibration or repair. Rods may be measured mechanically with depth gage.	Potentiometers may be removed for calibration or repair. Rods may be measured mechanically with depth gage.
Reliability and Durability	Excellent long-term and submerged conditions.	Poor performance history with large number of sensor failures on one project.
Ease/Cost of Installation	Installation in 3-inch borehole with grouting.	Installation in 3-inch borehole with grouting.
Ease/Cost of Monitoring	Direct linear conversion of voltage displacement.	Direct linear conversion of voltage displacement.
Availability	8 weeks	6 to 8 weeks

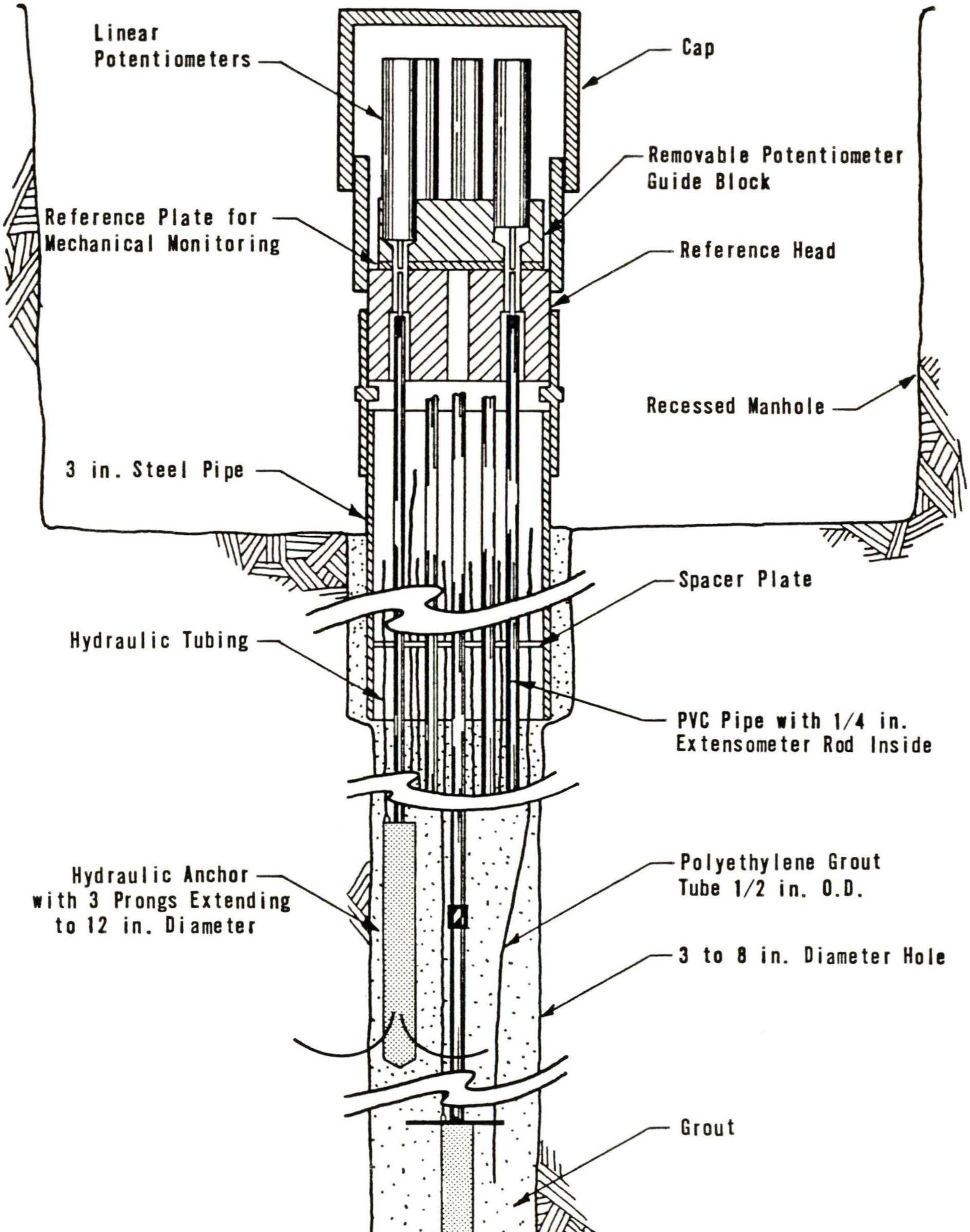


FIG. 3.1 Multiple-Position Rod-Type Borehole Extensometer

on the Atlanta Rapid Transit project due to the use of potentiometers and other electrical components which were inadequately sealed and were susceptible to moisture which condensed on these components.

Extensometers manufactured by Solinst Ltd and Slope Indicator Company have very similar design features. The components of both systems have been in operation for several years under severe conditions, including submergence for up to 4 years with a very low attrition rate. Slope Indicator also produces a hydraulically actuated Borros anchor which resembles a grappling hook when expanded. This anchorage system expands to a diameter of 12 inches and will, therefore, firmly embed itself into soil or soft rock, providing that the borehole is small enough. A properly encased linear potentiometer has a long life and is a relatively simple electrical sensor. The linear potentiometer should employ a cermet (ceramic-metal composition) resistor, rather than wire-wound to improve resolution. The displacement range required for an extensometer will vary, but 2, 4 or 8-inch ranges are common in geotechnical instrumentation. The packaging of the potentiometer is very important and contributes greatly to the overall reliability and cost. Sensors to be used underwater should be carefully sealed with O-rings or similar seals, but in the case of this coal waste embankment where the reference head is at the ground surface and is accessible for maintenance, careful potting of the electrical connections should suffice.

Methods exist other than borehole extensometers to remotely measure vertical deformations. One method involves the comparison of the fluid pressure within a container within the embankment with the fluid pressure in a container located at a stable reference point outside the embankment. Changes in elevation of the container within the embankment cause a pressure change to be transmitted via hydraulic tubing. A pressure measuring device then measures the pressure change which can be converted to a deformation. For a remotely monitored system, this pressure transducer would probably be an electrical pressure gage similar to those used in piezometers. The fluids commonly used in such systems include water, ethylene glycol, oil, or mercury. The primary advantages of these types of systems is that the tubing can be installed either during embankment construction or in a shallow trench after a bench is completed so that tubes or rods extending upward through the embankment fill are avoided. Sources of error for these systems are many and include temperature variations, contamination of the circulating fluid by gas or water, equipment complexity, and unsuitability for unattended remote monitoring.

There are several other methods of measuring vertical deformations commonly in use which do not lend themselves to remote monitoring. These include the U.S. Bureau of Reclamation settlement device, the reed switch/magnet device, and the inductance probe device. All of these devices and their variations use a graduated steel tape to measure the vertical movement of a casing at selected positions. The tape is raised and lowered by hand and some type of sensor is used to indicate the casing position. The difficulties associated with remotely and automatically measuring with these instruments preclude their use in an automatic data acquisition system.

3.2.3 Horizontal Deformations

Mass movements associated with instability of embankments or dams are often preceded by small but measurable deformations (strains) reflecting incipient failure. Generally, these deformations include a significant proportion of lateral translation. Sensors which can detect small horizontal deformations along a vertical borehole in a marginally stable mass provide one means for detecting the early stages of such instability. Sensor systems which have been used for detecting such deformations and instabilities include shear strips, electrolytic levels, strain-gaged deflectometers, and servo-accelerometer inclinometers.

Horizontal extensometers can be installed in a manner similar to vertical extensometers, except that horizontal boreholes must be drilled. This method, while used extensively in tunnels, has many disadvantages in an embankment. The primary disadvantages are the difficulty and cost of horizontal boreholes, limited information generated, increased risk of dam leakage, and the lack of a stable reference point. A horizontal borehole could easily miss intersecting a failure surface and indicate little movement before failure. Consequently, except in unusual circumstances, horizontal extensometers in boreholes are inappropriate for measuring horizontal deformations at refuse embankments.

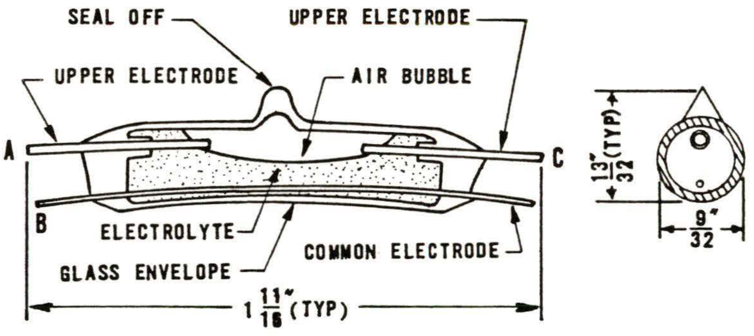
In some large dams horizontal extensometers or strain meters are placed in trenches along the crest of the dam to measure horizontal deformation parallel to the crest. The gages consist of sleeved steel rods connected in series with linear potentiometers to form a measuring chain. This method only provides information on horizontal movements parallel to the crest of the dam caused by settlement, lacks the sensitivity of other near-surface horizontal measuring devices, is relatively expensive and vulnerable to damage, and is not easily maintained if the embankment is raised.

Shear strips consist of resistors wired in parallel along the length of a flat plastic strip which is grouted into a borehole. Breaking the strip at any one point decreases the overall resistance of the strip by a known amount; measuring the decrease in overall resistance of the shear strip may be used to calculate the location of this break. The system "hardware" is relatively inexpensive, however, it provides only a one time indication of the location of movement of unknown magnitude. The shear strip only indicates the uppermost zone of movement which may represent a superficial movement, and thereby mask more significant deep movements. Thus, interpretation is very restricted. Shear strips are relatively delicate so that an inordinate degree of care is required during installation to avoid damaging the strip and they are very susceptible to water. Consequently, we do not consider shear strips to be particularly appropriate for the early warning and long-term monitoring systems discussed herein.

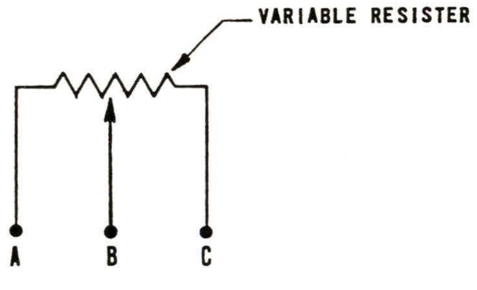
The remaining three sensor types, electrolytic liquid levels, strain-gaged cantilevers and servo-accelerometers, are all used in similar instruments for monitoring borehole distortion. Individual sensors are enclosed in a waterproof housing attached to a rigid tube or rod, typically two to fifteen feet long. These unit assemblies are connected in series by a universal joint so that individual sensors may rotate independently of adjacent sensors. The sensor assemblies are typically centered and oriented by guide wheels or skids in a grooved casing permanently installed and backfilled in a borehole. Alternately, orientation in smooth casing may be accomplished with torque rods. Measured sensor rotation is used to calculate incremental horizontal deformations along the borehole and deformation calculated for adjacent sensors may be summed to provide a deformation profile along all or part of the instrumented borehole.

Electrolytic liquid levels have been used infrequently to monitor surface tilts and borehole distortions. The level consists of a 0.5 to 4-inch long sealed glass vial partially filled with a liquid electrolyte and pierced by three electrodes as shown on Figure 3.2. The resistance between electrodes is controlled by the position of the air bubble and, consequently, by the tilt of the level. Tilt is normally measured as a function of AC voltage output as compared to a precision voltage input. Available levels have ranges of ±50 arc seconds to ±30 degrees with sensitivities of 0.1 arc seconds to 15 arc minutes, respectively. In one geotechnical monitoring application a level with linear range of ±40 arc minutes and a sensitivity of 2 arc seconds was successfully used (Cooke and Price, 1974). Long-term drift for these devices has been reported to range from ±0.3 percent to ±3 percent of full-scale. Temperature induced variations average 0.2 percent of full-scale deflection per °C and the liquid level's cross-sensitivity is relatively high. Primary disadvantages of these devices are their relatively large long-term drifts, temperature induced variations, and cross-sensitivity relative to strain-gaged cantilevers and servo-accelerometers. It is reported by the manufacturer that these devices have a finite life span of 10,000 hours or 14 months under continuous power. In instances where these sensors have been used, they have been discontinuously powered and sensors have been in operation for over 2 years without failure under submerged conditions (Wilson, 1979). However, for an automatic monitoring scheme, discontinuously powering a sensor complicates automatic data acquisition. Furthermore, in a borehole installation, initial sensor orientations may be several degrees from vertical so that a sensor with a wider range, and consequently poorer sensitivity than is desirable, would be necessary. Although electrolytic liquid levels are available from the Fredericks Co., a U.S. manufacturer, they are not routinely used by geotechnical instrument manufacturers and, consequently, significant design and trouble-shooting efforts would be required to provide a working borehole instrument. Due to the above deficiencies we have not pursued the use of this sensor. We believe, however, that it could in the future provide a less expensive and suitably precise alternative to the sensors discussed in the following paragraphs.

The in-place borehole deflectometer, made by Terrametrics, incorporates a strain-gaged flexible steel cantilever which acts at the pivot point for adjacent sections of rigid stainless steel tubing, as shown on Figure 3.3. Bending strains induced into the cantilever by borehole deformations are sensed by four resistance strain gages epoxy bonded to the cantilever. Changes in resistance of the gages are linearly proportional to the offset of the cantilever from its unflexed position parallel to the axis of the pipe. Therefore, as with the electrolytic levels, output data from a series of deflectometer sensors may be mathematically manipulated and then summed to provide a deformation profile for the instrumented portion of the casing. General instrument characteristics of the Terrametrics deflectometer are presented on Table 3.3. Specifications for the deflectometer are shown on Table 3.4. The instrument, as shown on Figure 3.3, is centered in the casing with a series of nylon ring spacers located near the sensors. Since the instrument lacks wheels, it may be installed in plain, ungrooved casing; however, this installation procedure results in much less precise repositioning of the sensors if sensor strings are for any reason removed or moved in the casing. The rings, being somewhat flexible, may permit some lateral shifting of the sensors in the casing which reduces system sensitivity. The relatively large diameter of the connecting tubing, generally 2 inches, tends to limit the amount of borehole distortion which may occur before contact is made with the tubes, which could subsequently result in erroneous deflection data. For gage lengths in excess of 10 feet, tube diameters of 2 inches are required to provide enough rigidity to bend the steel cantilever. For gage lengths less than 10 feet, the tube size may be reduced to 1¼-inch.



ELECTROLYTIC LIQUID LEVEL



ELECTRICAL ANALOGUE

FIG. 3.2 Electrolytic Level

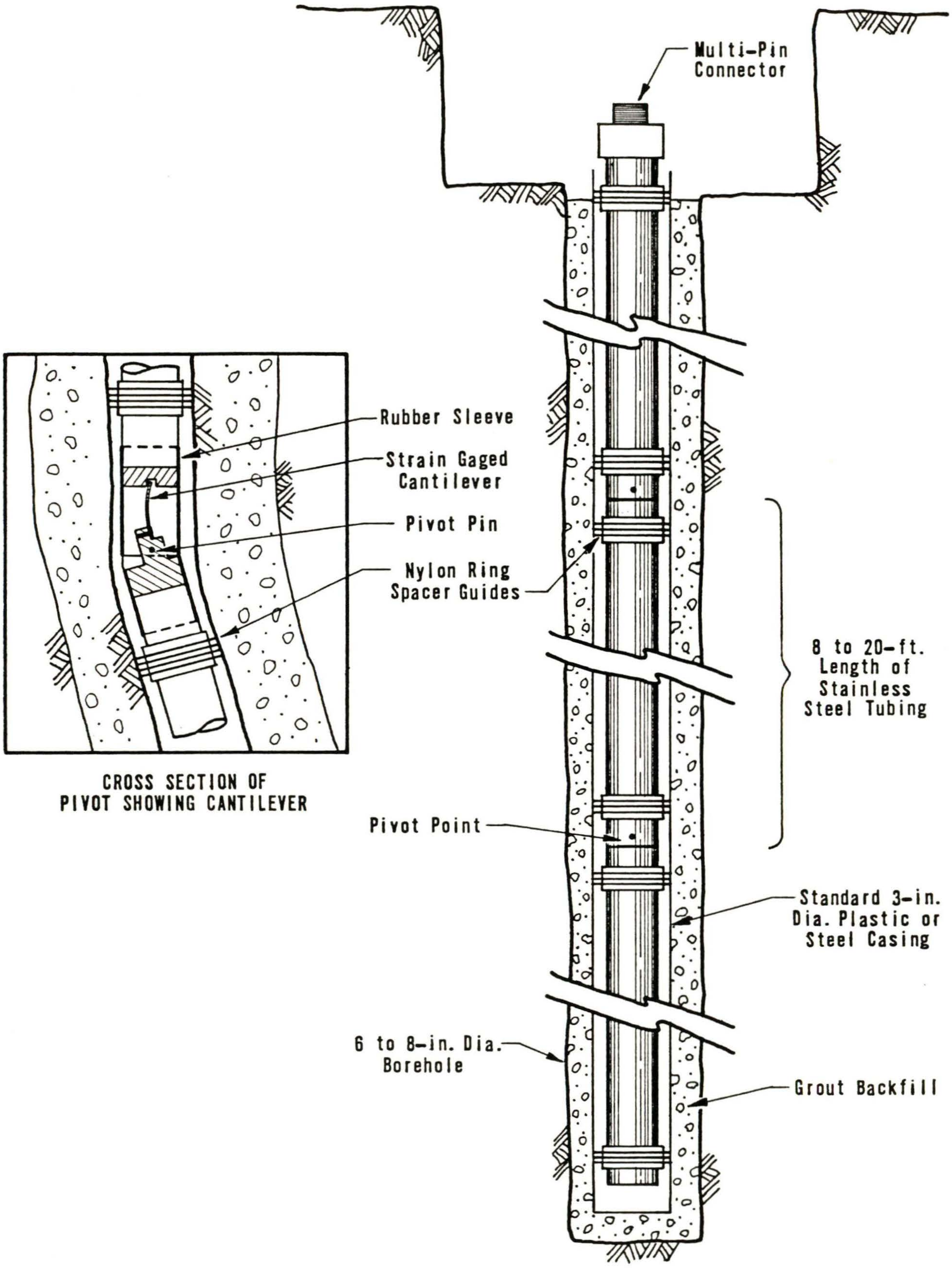


FIG. 3.3 In-Place Borehole Deflectometer

TABLE 3.3

Description of Borehole Horizontal Deformation Monitoring Devices

Instrument Type	Instrument Model	Instrument Characteristics
Servo-Accelerometer Sensor	Slope Indicator Co. In-Place Inclinometer	Sensors consist of uni- or bi-axial servo-accelerometers interconnected with rigid rods. All stainless steel construction. Number of gages in hole limited to number of cables which will fit in casing. Maximum gage rod length of 20 feet. Recoverable from borehole. Problems with long-term zero drift have been noted.
	Terra Technology In-Place Inclinometer	Same as above, except incorporates a variety of metals subject to corrosion. Construction of guide wheels and interconnecting tubing less robust than above.
Strain-Gaged Cantilever Sensor	Terrametrics, Inc. In-Place Deflectometer	Sensors consist of electrical resistance strain-gaged cantilevers stressed by the deflection of adjacent interconnecting tubes. The interconnecting stainless steel tubes are 1-1/4-inch O.D. Limited to 9 sensors and 180-foot depth due to lead wire limitation. Zero drift problems have been reported with similar strain-gaged devices. Useful for nonvertical holes.

TABLE 3.4

Specifications of Borehole Horizontal Deformation Monitoring Devices

	Slope Indicator Co. In-Place Inclinometer	Terra Technology Corp. In-Place Inclinometer
Model Number	50435	MP-10 Series
Range	±30° from vertical	±90° from vertical
System Specifications	Sensitivity ±.001 inch or ±1.7 arc second. System sensitivity ±.006 inch. Thermal coef. ±.002 in/°F.	Gage sensitivity ±.001 inch or ±1.7 arc sec. System sensitivity ±.006 inch. Thermal coef. ±.002 in./°F.
Power Requirements	+5 to +18 VDC -5 to -18 VDC	±5 to ±18 VDC or ∓5 to ∓8 VDC
Output	Range 0 to 12 VDC. Resolution .1mv/.001 inch for 10-foot gage length.	Not known
Wires per Sensor	5 to 6	5 to 6
Calibration and Maintenance	Calibration checked by removing from hole and monitoring with portable inclinometer.	Calibration checked by removing from hole and monitoring with portable probe inclinometer.
Reliability and Durability	All exposed parts stainless steel. In continuous use in some projects for 3 years.	Subject to serious corrosion due to mixed metal construction. Thin interconnecting rods easily damaged. Electrical shorts reported in numerous installations. In continuous use on some projects for 2 years.
Ease/Cost of Installation	Installed in 3.5 or 2.75 inch OD grooved casing. Complex connection of hardware.	Installed in 3.5 or 2.75-inch OD grooved casing. Complex connection of hardware.
Ease/Cost of Monitoring	Linear conversion to displacement.	Linear conversion to displacement.
Availability	6-8 weeks	6-8 weeks

TABLE 3.4 (cont)

Specifications of Borehole Horizontal Deformation Monitoring Devices

	Terrametrics, Inc. In-Place Deflectometer
Model Number	
Range	±6° from axis of each sensor
System Specification	Gage sensitivity ±.0005 inch or 1 arc sec. System sensitivity ±.006 inch. Thermal coef. ±.002 in./°F.
Power Requirements	6 to 12 VDC
Output	Range 0 to 10 VDC. Resolution 1mv increments
Wires per Sensor	4
Calibration and Maintenance	Calibration checked by monitoring adjacent grooved casing with portable probe inclinometer
Reliability and Durability	In continuous use on some projects for 6 months in salt water
Ease/Cost of Installation	Installed in 3-inch plastic or steel ungrooved casing
Ease/Cost of Monitoring	Linear conversion to displacement
Availability	6-8 weeks

Resistance strain-gaged sensors have been recognized to have an inherent sensitivity of 1 arc second, somewhat less sensitive than electolytic liquid levels, and slightly more sensitive than servo-accelerometers. The precision of the deflectometer system is reportedly similar to that of portable probe inclinometers, approximately 1 in 10,000. However, most bonded resistance strain-gages exhibit serious long-term drift problems due to creep of the resistance elements and bonding agents. The creep properties are aggravated on an in-place installation where the gages are under long-term, constant stress while being continuously energized. Data on the drift characteristics for this particular system have not been recorded and the magnitude of its zero-drift is not known. At least one string of sensors was installed for a period of 6 months in a saltwater estuary to monitor tidal induced slope deformations and exhibited no apparent zero-drift problems although an attempt was not made to determine creep rates. Due to the moderate resistances of the strain gages (350 ohms each) and long lead wire lengths such as will occur at most damsites, seasonal and daily temperature variations of the surrounding soil mass may alter the voltage measurements for each sensor element. The effects of long lead length and temperature variations are, to a large degree, compensated by using a 6-wire system for monitoring the full Wheatstone bridge circuitry. The use of resistance strain gages also requires the incorporation of some additional voltage supply and signal conditioning circuitry in the data acquisition system. Similar circuitry is required for the electrolytic levels and resistance piezometers discussed elsewhere.

The in-place inclinometers made by the Slope Indicator Company in Seattle and Terra Technology Corporation in Redmond, Washington both utilize servo-accelerometers for monitoring inclination changes. Servo-accelerometers consist of an electromagnetic coil on a cantilevered flexure-pendulum suspended in a magnetic field, as shown on Figure 3.4. Movement of the pendulum out of the magnetic field is sensed by a servo-mechanism which generates a current through the coil in the pendulum to maintain the pendulum stationary in the magnetic field. The current required is linearly proportional to the inclination of the pendulum. General descriptions of the operating characteristics of the two available in-place inclinometers of this type are provided on Table 3.3. As with the deflectometer, voltage output from the sensors are linearly proportional to angular change or displacement. Consequently, a profile of borehole deformation for the instrumented portion of the borehole may be computed by adding the component deflections of all the sensors. Servo-accelerometer sensors have a sensitivity of approximately 2 arc seconds for a range of ±30 degrees to ±90 degrees, depending on the manufacturer. Temperature induced variations amount to approximately 5 arc seconds per ^{o}C.

In evaluating the relative merits of servo-accelerometer based in-place inclinometers from the two manufacturers, we generally consider the packaged sensor from the Slope Indicator Company to be better engineered for precision long-term use under adverse environmental conditions. Terra Technology in-place inclinometers, used for 2 years on a recent Bureau of Reclamation project, (Carter, 1979), were found to be constructed with, 1) lightweight stainless steel gage length tubing which was easily bent during installation, 2) low quality plastic guide wheels attached with aluminum pop rivet "axles" to a steel spring, 3) an aluminum casing which was found in some installations to disintegrate as a result of cathodic corrosion between the aluminum and steel, and 4) intermittent electrical shorts in some 20 percent of the installations, which resulted in serious creep problems in the sensors. It has also been reported on this as well as several other projects (Dekker, 1979), that Terra Technology is slow to respond to users needs with regard to instrument fault finding and repair or replacement where field conditions so require.

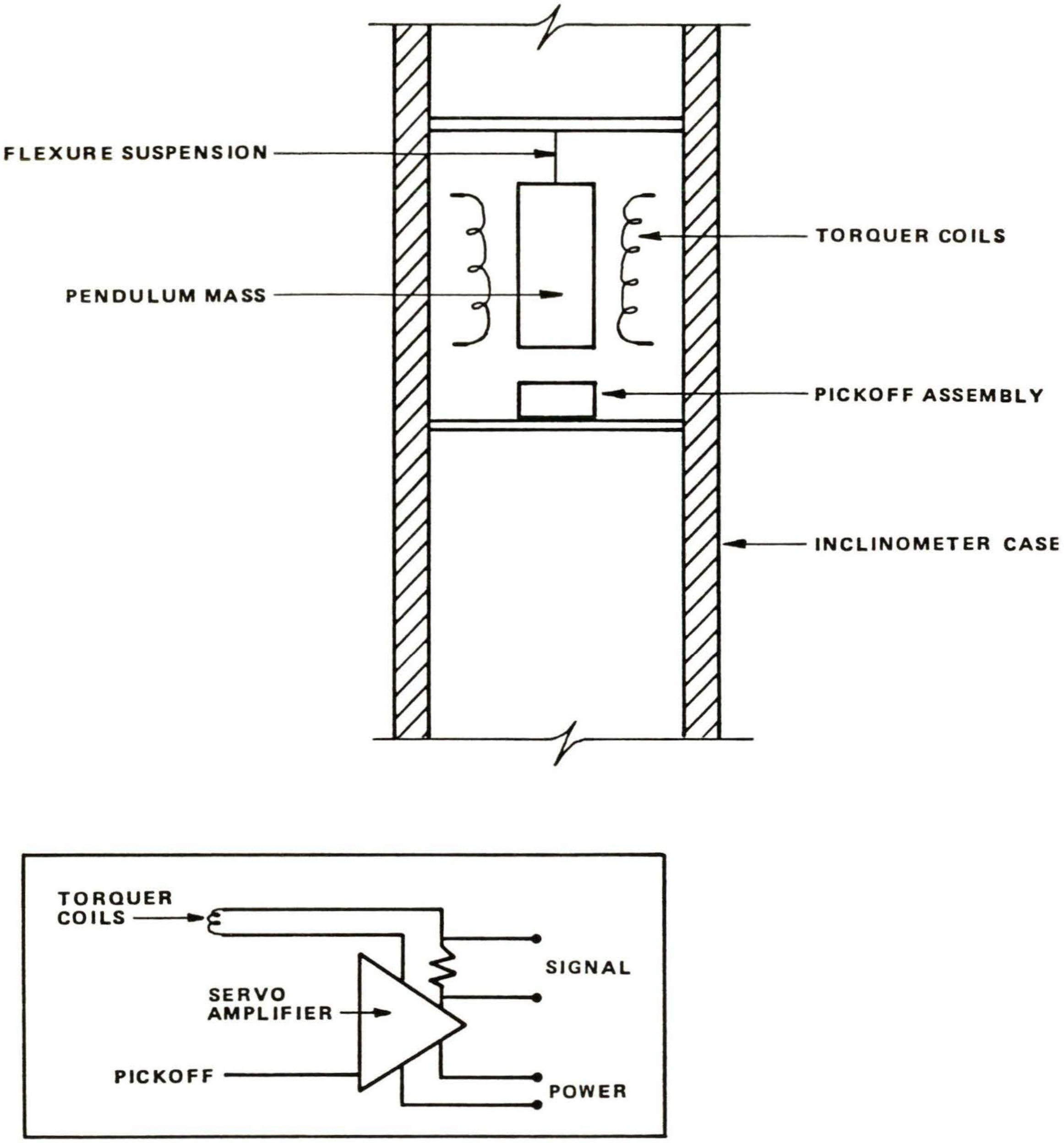


FIG. 3.4 Servo-Accelerometer for Inclinometer or Tilt Measurement

Slope Indicator in-place inclinometers were also installed on the Bureau of Reclamation project referred to above and had been in operation for approximately 6 months at the time of our conversation with personnel who had used this equipment. These instruments were considered to be of superior quality construction with all stainless steel construction, including stainless steel wheels, bearings and wheel carriages and stainless steel gage length tubing of adequate thickness to resist bending during installation. Some 5 percent of the sensors experienced cable failure due to a faulty connector sealing; however, the sensors were rapidly replaced by the manufacturer upon notification by the Bureau of Reclamation.

3.2.4 Pore-Water Pressures

Increased pore-water pressures in an embankment are commonly related to decreased stability. The important place to measure the pore-water pressure is along the failure surface, but there are generally several potential failure surfaces within the embankment. Thus, many piezometers may be required to adequately monitor pore-water pressures, and these piezometers must be distributed throughout the embankment to measure this parameter. There are four main types of piezometers used in geotechnical instrumentation: open standpipe, twin-tube hydraulic, pneumatic, and electric. Open standpipe piezometers are simple, whereas all others are more complex and subject to limitations. Some features and specifications are listed in Tables 3.5 and 3.6.

Open standpipe piezometers are simple plastic or metal pipes with the bottom section perforated which are placed in a borehole. Sand is placed around the pipe tip and a clay or Portland cement seal placed above the sand. Occasionally, a porous stone filter is placed at the end of the pipe. Usually only one standpipe can be effectively placed in a single borehole due to sealing difficulties. Pipe diameter varies from ¼-inch to about 3 inches. Standpipe piezometers are reliable if installed properly, but have a very slow response time if installed in impermeable material. Standpipe piezometers are monitored using manual techniques and require some other equipment to be used in an automatic or remote monitoring system.

Twin-tube hydraulic piezometer systems have proven to be very reliable over the past 30 years; however, they are somewhat cumbersome to monitor and require at least annual maintenance and possess severe limitations with respect to location and elevation of the sensor, tubing, and measuring station. Hydraulic piezometers consist of two water-filled tubes, one leading into and one leading out of a porous-stone-tipped piezometer placed below the groundwater level. Water pressure in the tubes and tip are measured at the end of one of the tubes with either an electrical pressure transducer, manometer, or Bourdon gage. The hydraulic piezometer tubing is capable of withstanding a negative pore-water pressure of up to 1 atmosphere before a break occurs in the hydraulic connection. To prevent such a break, no portion of the tubing or the tip should be more than about 15 feet above the groundwater level.

The primary advantage of a hydraulic piezometer is that the most delicate portion of the system, the pressure measuring device, can be located in an accessible, safe, convenient place. In addition, the twin-tube hydraulic piezometer permits water sampling, permeability testing around the tip, determining flow paths by introducing dyes through the tip, and evaluation of in-situ stress (Vaughan, 1974).

TABLE 3.5

Description of Pore-Water Pressure Transducers

Instrument Type	Instrument Model	Instrument Characteristics
Hydraulic Piezometer	Solinst, Canada, Ltd. Twin-Tube Hydraulic Piezometer	Simple twin-tube hydraulic system. Readout and tubing must be less than 15 feet above water level. Susceptible to freezing. Readout with electric pressure transducers. Piezometer may be used by site personnel for determining in situ stress, permeability, flow path and taking water samples.
Vibrating Wire Electrical Piezometer	Irad Gage Company PW Vibrating Wire Piezometer	Vibrating wire piezometer incorporates vibrating wire strain gage and measures frequency of oscillation. Pore pressure proportional to square of frequency. Less sensitive to errors from long lead lengths, bad contacts, leakage, and temperature gradients than resistance-gaged piezometers. Uses a flexible stainless steel diaphragm. Diameter 1 to 1.75 inch, length 3 inches.
Electrical Resistance Piezometer	Slope Indicator Co. 564 Series Electrical Piezometer	Electric piezometer incorporating a silicon sensing diaphragm with diffused full bridge semi-conductor resistance strain gages. Diameter 0.75 inch, length 8 inches.
	Terrametrics, Inc. Electrical Resistance Piezometer	Piezometer incorporating a stainless steel diaphragm with epoxied 350 ohm strain gages in a full bridge configuration. Strain gage configuration reduces adverse affects of lead length. Diameter 1.2 inch, length 4 inches.
	Terra Technology PE Series 1000 Electrical Piezometer	Piezometer incorporating full bridge semiconductor resistance strain gage. Uses 2 micron stainless steel mesh filter and nickel steel bellows. High resistance gages reduce adverse affects of lead length. May be modified with a single hydraulic flushing tube to purge filter stones of debris or gas or with redundant hydraulic piezometer as check on functioning. Diameter 1 inch, length 6 inches.

TABLE 3.6

Specifications of Pore-Water Pressure Transducers

	Solinst, Canada Ltd. Hydraulic Piezometer	Irad Gage Co. Vibrating Wire Piezometer
Model Number		PW
Range	-7 to +260 psi	25, 100 500 psi
System Specification	Accuracy ±0.25% F.S. Sensitivity 0.01% F.S.	Accuracy ±0.5% F.S. Sensitivity 0.01% F.S. Temperature compensated
Power Requirement	6 to 18 VDC	110 VAC or 18 VDC for readout. Pulsed 5 VDC from readout to sensors.
Output	125 mV FS in units of 0.4 mV	Variable frequency 625-5500 Hz return pulse converted to BCD.
Wires per Sensor	4	2
Calibration and Maintenance	Periodic de-airing by onsite person. No calibration necessary. Must be protected from freezing.	Calibration by factory may be checked in field if installed in open casing. No maintenance required.
Reliability and Durability	Excellent record. Corrosion resistant. Electrical sensor accessible in readout house.	Less susceptible to creep or lead length errors than resistance gages. Good 2-year performance record.
Ease/Cost of Installation	Requires more careful installation than other systems. Requires complex transducer system.	Relatively easy to install in borehole or trench.
Ease/Cost of Monitoring	Leads 3000 feet maximum. Complex de-airing requirements.	Requires complex signal conditioning to convert frequency to digital or analog voltage. Nonlinear conversion to psi.
Availability	4-6 weeks for tips. 10 weeks for readout.	6 to 8 weeks

TABLE 3.6 (cont.)

Specifications of Pore-Water Pressure Transducers

	Slope Indicator Co. Electrical Piezometer	Terrametrics, Inc. Electrical Resistance Piezometer
Model Number	564 Series	
Range	25, 50, 100, 250 500, 1000 psi	1000 psi
System Specification	Accuracy 0.5% FS Sensitivity 0.01% FS Temperature compensated	Accuracy 0.5% FS Sensitivity 0.01% FS
Power Requirement	Readout 12 VDC. Voltage for sensor ±1.875 VDC.	Readout 12 VDC. Gage voltage 10 VDC.
Output	Range 0 to 74.5 mV	Range 0-10v in 1 to 10mV increments.
Wires per sensor	4	6
Calibration and Maintenance	Calibration by factory may be checked in field if installed in open casing. No maintenance required.	Calibration by factory may be checked in field if installed in open casing. No maintenance required.
Reliability and Durability	May be more susceptible to creep than other systems. Corrosion resistant parts. No long-term performance records.	May be more susceptible to creep than other systems. Corrosion resistant parts. No long-term performance records.
Ease/Cost of Installation	Relatively easy to install in borehole or trench.	Relatively easy to install in borehole or trench.
Ease/Cost of Monitoring	Circuitry eliminates lead length errors. Linear conversion to psi. Requires standard resistance strain gage signal conditioning.	Circuitry eliminates lead length errors. Linear conversion to psi. Requires standard resistance strain gage signal conditioning.
Availability	4-6 weeks	4-8 weeks

TABLE 3.6 (cont.)

Specifications of Pore-Water Pressure Transducers

	Terra Technology Electrical Piezometer
Model Number	PE Series 1000
Range	250,500,1000, 2000 psi
System Specification	Accuracy 0.1% FS. Sensitivity 0.01% FS.
Power Requiremnt	Readout 12 VDC. Voltage to gage 10 VDC.
Output	Range 0-10V in low increments.
Wires per Sensor	6
Calibration and Maintenance	Calibration by factory may be checked in field if installed in open casing. No maintenance required.
Reliability and Durability	May be more susceptible to creep than other systems. Corrosion resistant parts. No long-term performance records.
Ease/Cost of Installation	Relatively easy to install in borehole or trench.
Ease/Cost of Monitoring	Circuitry eliminates lead length errors. Linear conversion to psi. Required standard resistance strain gage signal conditioning.
Availability	4-8 weeks

Electrical piezometers generally monitor water pressure against flexible diaphragms which are calibrated to relate the amount of flexure to pressure. Many different methods are used to measure this deflection in commercial transducers, such as electrical resistance strain gages, tensioned vibrating wires, linear variable differential transformer, quartz capacitance, and magnetostrictive. The two most common methods used by geotechnical instrument manufacturers are the resistance strain gage and vibrating wire.

European manufacturers of vibrating wire piezometers have been producing high quality instruments for 20 to 30 years, whereas U.S. manufacture of this type of instrument only began less than 10 years ago. A vibrating wire piezometer (Figure 3.5) consists of a housing, metal diaphragm, steel wire stretched between the housing and diaphragm, and magnet-coil assembly(s) for "plucking" the wire and sensing its vibrational frequency. The method of "plucking" and measuring the frequency varies between manufacturers and the experience and reputation of one manufacturer does not necessarily apply to others. The major European manufacturers include: Maihak of Germany, Telemac of France, and Geonor of Norway. The only U.S. manufacturer is Irad Gage Company. The major advantages of vibrating wire piezometers are stable, long-term operation and insensitivity to lead resistance with long electrical leads. The electrical resistance piezometers utilize either electrical resistance strain gages bonded to a metal diaphragm, or a semiconductor gage fused into a silicon diaphragm. On Table 3.5, three commonly available U.S. manufactured electrical resistance strain gage piezometers are described. Specifications are given on Table 3.6.

All resistance piezometers utilize the Wheatstone bridge circuit to provide an increase in voltage output proportional to deflection of the diaphragm. Their advantage is the lower cost of the sensor and ease in measurement. The major disadvantage is long-term sensor drift, the influence of long electrical leads, and susceptibility to moisture. Sensor drift is accentuated when the gages are continuously powered. None of the U.S. manufacturers have supplied long-term performance records which indicate the long-term creep properties of the gage in a geotechnical environment.

A number of pneumatic piezometers are available, each model being slightly different in design of the tip, number of tubes, or measuring system. The basic idea is to supply a gas pressure to counterbalance pore-water pressure at a diaphragm valve. The gas pressure is thus a measure of the pore-water pressure. One advantage of the system is that long tubes can be placed in the ground for remote monitoring and only the tip is buried and inaccessible; the measuring transducer is above ground. Normally, Bourdon tube gages are used to measure the gas pressure, but an electrical pressure transducer can be used instead. The disadvantages to the pneumatic systems are the need for a supply of pressurized gas and the unsuitability for direct electrical readout.

3.2.5 Earth Stress Sensors

Earth stress measurements provide an indication of the stresses at various points within the embankment and the interaction between various embankment materials. Since these types of instruments measure total stress (i.e., effective stress + pore-water pressure) at a single point, the instrument location is quite important and must be carefully chosen. Earth fill dams with impermeable or zoned cores are often monitored with earth pressure cells to provide data for confirming design or evaluating load transfer and arching characteristics between zones.

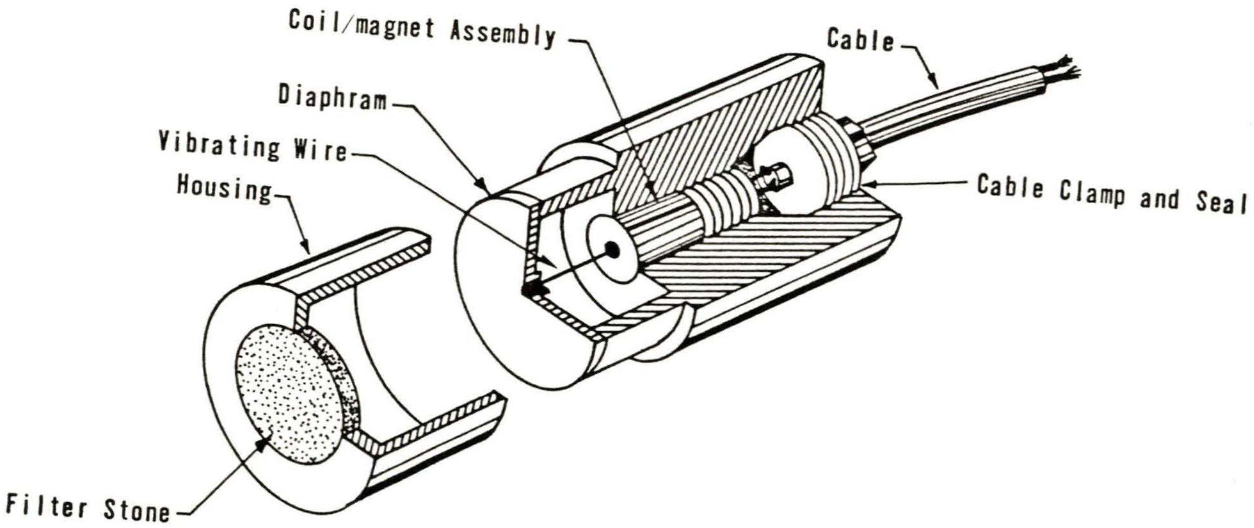


FIG. 3.5 Vibrating Wire Piezometer

A number of different earth pressure cells are available which utilize different sensors to measure the pressure; however, each type is designed to measure stress in one direction only with minor sensitivity to stress in other directions. In general, a metal diaphragm is used to detect the earth pressure. The resulting diaphragm deflection is measured, or the pressure change within the cell is measured. One type uses electrical resistance strain gages or a vibrating wire gage to measure diaphragm deflection, while other types use hydraulic fluid to transmit pressure changes to a nearby pressure transducer. Hanna (1973) discusses the mechanical aspects of many types of earth pressure cells, along with the various restrictions associated with their use.

Earth pressure cells have had a mixed success rate, depending on the manufacturer, type, specific use, and care taken by the user. The major disadvantage of this instrument is the inability to match the moduli of the embankment material, material immediately surrounding the cell, and the cell itself. The cells are most effective when installed during embankment construction and nearly impossible to install down a borehole.

When oil-filled earth pressure cells are monitored by electrical means, methods similar to those discussed in Section 3.2.4 on piezometers are used. Irad Gage Company produces this type of cell and utilizes a vibrating wire gage to monitor hydraulic pressure. Terra Technology produces a cell which utilizes resistance strain gages to monitor hydraulic pressure within the cell.

3.2.6 External Influence

Embankments in coal waste impoundment structures are subject to changes in external influences, such as: seismic loading, a slide in an abutment, subsidence of the foundation, and the water impounded by the structure. Potential slides into the impoundment are either evaluated during design, or some corrective action performed during construction , or a separate monitoring system established for the potential slide. Subsidence of the embankment is usually monitored by deformation instruments. Seismic loads are evaluated by measuring ground motion during an earthquake and then calculating the additional forces generated. Since earthquakes are unexpected and short-term phenomenon, special instrumentation systems are installed which are triggered by the earthquake whenever this parameter is critical.

The force generated by the impounded water is an important parameter in embankment stability evaluation. The level of water impounded is related to the pressure on the embankment and fluctuates on a daily basis. Water level is particularly important at times of flooding because of the possibility of overtopping. Water level measurement is difficult for two reasons. First, a stable reference point is difficult to establish in the middle of a large impoundment; second, construction at this part of the site is usually very active, which makes permanent installations difficult. There are many different methods of measuring water level in the pond. The simplest method uses a graduated steel pipe fixed at bedrock and extending through the fines. Water level can be measured by visual examination or surveying. This method, however, does not lend itself to automatic recording.

Three methods which can be used for remote, automatic monitoring are: measuring pressure of the water in the pond, reflective measurement of the water surface, and a flotation device. The first method is simply a form of open standpipe with an electrical piezometer in the bottom which measures the pressure of the overlying water. The second method uses an ultrasonic device which monitors the time it takes for a signal to be reflected from the water surface. The ultrasonic sensor sits 0 to 5 feet above the water surface on a stable platform. The major disadvantages to this system is the cost of establishing a stable platform and the need to frequently reset the platform because of a rising fines level. The third method uses a standard stillwell and float-type device. The float is attached by cable to a pulley which has a rotary potentiometer. As the water level changes, the float rotates the pulley and the potentiometer. The major disadvantage of this system is the expense of building and maintaining a stable stillwell which will not be affected by ice formation or debris.

3.2.7 Seepage/Flow Measurement

All dams are imperfect seepage barriers. However, unacceptable or major increases in seepage volume may portend failure of the dam. Therefore, measurement of seepage volume is desirable in an automated or remote monitoring system. Since seepage commonly occurs on portions of the embankment which are removed from regular human activity, automatic monitoring can provide important information on this often neglected parameter. Typically, seepage volumes are measured by collecting and diverting the seepage water through or over a calibrated opening such as a flume or weir. The height of the water is proportional to the flow volume. Of the two openings, weirs are easiest and least expensive to construct adjacent to an embankment. A typical weir monitoring station consists of a concrete, metal, or plywood bulkhead with a "v" or rectangular-shaped notch on one side over which the seepage water flows. The "v"-shaped notch is most often used because it is most sensitive to changes in flow rate. The height of water above the notch base may be measured visually on a vertical scale, or may be recorded in a stillwell by mechanical or electrical fluid level measuring devices. Two of these devices, the ultrasonic water level and the Leupold & Stevens float recorder, have been discussed in Section 3.2.6. Both devices require a stable platform directly above the weir. The ultrasonic device is a fairly delicate instrument which requires an environmental enclosure and regular maintenance. The float device is a rugged well-proven mechanical unit which incorporates a strip chart recorder driven by a 6-month, spring-wound clock.

3.2.8 Meteorological Instruments

Temperature and precipitation may influence embankment stability causing both freeze-thaw effects and increased impoundment of water. Consequently, these variables are commonly measured as part of complete stability monitoring system. Frequently, they are measured manually with hand held or mounted thermometers and graduated rain containers. For a remote or automatic data acquisition system these parameters should be monitored by electrical sensors. Barometric pressure does not directly affect embankment stabilty, but can affect the performance of any instruments which measure pressure.

A large variety of suitable temperature sensors are available for monitoring air temperatures at selected locations. The selected sensor should have a minimum range of -30 to +150 ^{o}F, with a sensitivity of at least 2 ^{o}F. Many sensors exist which fit these requirements, including thermocouples, thermistors and resistance temperature devices.

Two types of automatic precipitation measuring systems are available. One system uses a large bucket to collect rainfall and a float device to measure water height. The Leupold & Stevens Model 71 Type A water level recorder is a good example of this system. A rotary potentiometer is attached to the float pulley to electrically measure the water level.

The second type of precipitation monitor is a tilting bucket with a mechanical counter mechanism which produces a binary coded decimal (BCD) output signal. While this second type is the preferred method on remote meteorological stations, most automatic data loggers require special modification to interface with this type of instrument.

Barometers are available in many different configurations, using a variety of measuring modes. The most common type is the mercury barometer used in laboratories. This type is expensive and not very suitable for electrical monitoring. A common type used at meteorological stations is a quartz diaphragm-type manufactured by Setra Systems. This barometer measures pressure as a change in capacitance across a pair of quartz diaphragms on which platinum electrodes have been placed. The quartz diaphragms are slightly concave and are welded together so that a change in distance between diaphragms results in a change in capacitance. The transducer has an inherent sensitivity of 0.1 millibars over a range of 800 to 1100 millibars (11.6 to 16 psi).

3.3 Sensors Suitable for Use with Automatic Data Acquisition Systems

The previous sections described sensors suitable for measuring various geotechnical parameters. In this section we will discuss various sensors used in these instruments and their applicability to inclusion in an ADAS. While there are a great number of instruments, only a handfull of sensor or transducer-types are normally used within them. For example, the tiltmeter may utilize the same servo-accelerometer sensor as the in-place inclinometer; the vibrating wire sensor has been used in piezometers, earth pressure cells, inclinometers, and load cells.

To be useful in almost any ADAS a sensor, or at least some part of the instrument, must be electrical. The advantage of an electrical system is that many different instruments can be used and readings taken quickly. The electrical sensor need not necessarily be in the immediate proximity of the parameter being measured. For example, a pneumatic piezometer could have an electrical sensor at ground surface in order to modify it for use in an ADAS.

Some common electrical sensors used in geotechnical instrumentation include: servo-accelerometers, precision rotary and linear potentiometers, foil-type electrical resistance strain gages, resistance wire gages, piezoelectric and magnetic accelerometers, vibrating wire gages, linear variable differential transformers, magneto-restrictive gages and various temperature sensors.

Each sensor, with the exception of thermocouples, must be provided with some type of excitation power and the output must be conditioned before the data logger or computer can accept the data. Excitation and conditioning requirements vary considerably between sensor type, but, in general, resistance sensors are the easiest to interface. Increasingly, instrument manufacturers are adding electronics to the sensors to provide better quality excitation and signal conditioning for the sensor. The purpose of this is to both increase accuracy and reduce the sophistication of the readout. In some instances this increasing sophistication has resulted in instruments which are more easily interfaced to data loggers. However, in other cases, it restricts the sensor readout to a special unit built by the instrument manufacturer. In some cases the instrument has become so sophisticated that its inclusion in an ADAS must be preceded by careful study of all components of the ADAS, and possibly by experimentation. This is particularly true for those instruments which produce a digital output.

3.4 Automatic Data Acquisition Systems

3.4.1 General

The terms automatic, remote and unattended need to be defined in the context of this report. An automatic system is one that measures the output of sensors on a prearranged schedule. A remote system is any system which has the measuring instrument more than a few feet from the sensor or, in the case of subsurface sensors, more than a few feet from the top of the borehole. Almost any system which has more than one instrument will be a remote monitoring system. The exact distance involved in a "remote" system will have a major affect on the components selected for the system. Where the discussion would be confusing, we have attempted to define the distances involved. Unattended refers to the absence of direct human assistance in routine monitoring.

A convenient way to explain the different equipment configurations is by describing some previously designed systems and explaining the advantages and disadvantages of each with respect to site conditions at a coal waste impoundment. The simplest system that is commercially available is a single sensor-type with an automatic monitor. Signal conditioning and control circuits are contained in a single unit which may also contain a display and possibly a data recorder. Figure 3.6 shows a block diagram of this type of system; the Slope Indicator Model 56420 Electro/Piezo Scanner Recorder. Up to 10 channels can be scanned (without an expansion module) at a selected time interval. The data is automatically printed on metallic-coated paper tape for unattended operation. The disadvantage of this system is that somebody must go into the field periodically and retrieve the tape, and the system is generally limited to one type of sensor per recorder. The other disadvantage is that the information cannot be quickly assessed in the event of a developing instability. These systems are usually designed and built for a specific instrument and purpose by the instrument manufacturer (in this case, water well monitoring during a drawdown test).

3.4.2 Interrogatable Remote System with One Type of Sensor

The second type of system is slightly more sophisticated and has the benefit of providing data on command from a long distance away (Figure 3.7). The sensor or multiple sensors are sampled by a monitor which contains the scanner, signal conditioning and control circuits along with a printer or recorder. Remote access to the monitor is accomplished by a telephone connection and scanning is initiated by a telephone call. The degree of sophistication of the monitor is usually dependent on the manufacturer as well as the type of signal accepted. Of course, these systems require a nearby telephone line. One disadvantage of this type of system is that extensive modification may be needed for more than one type of input signal.

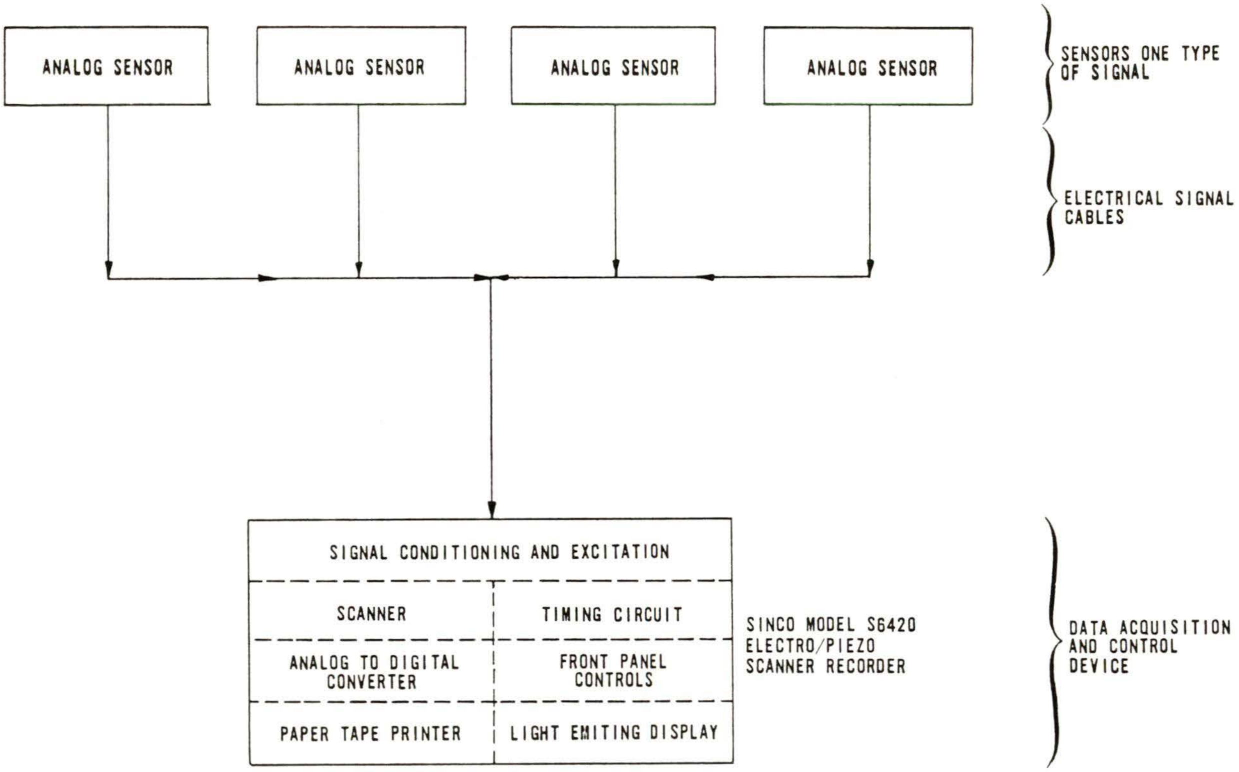


FIG. 3.6 On-Site Unattended Data Recorder

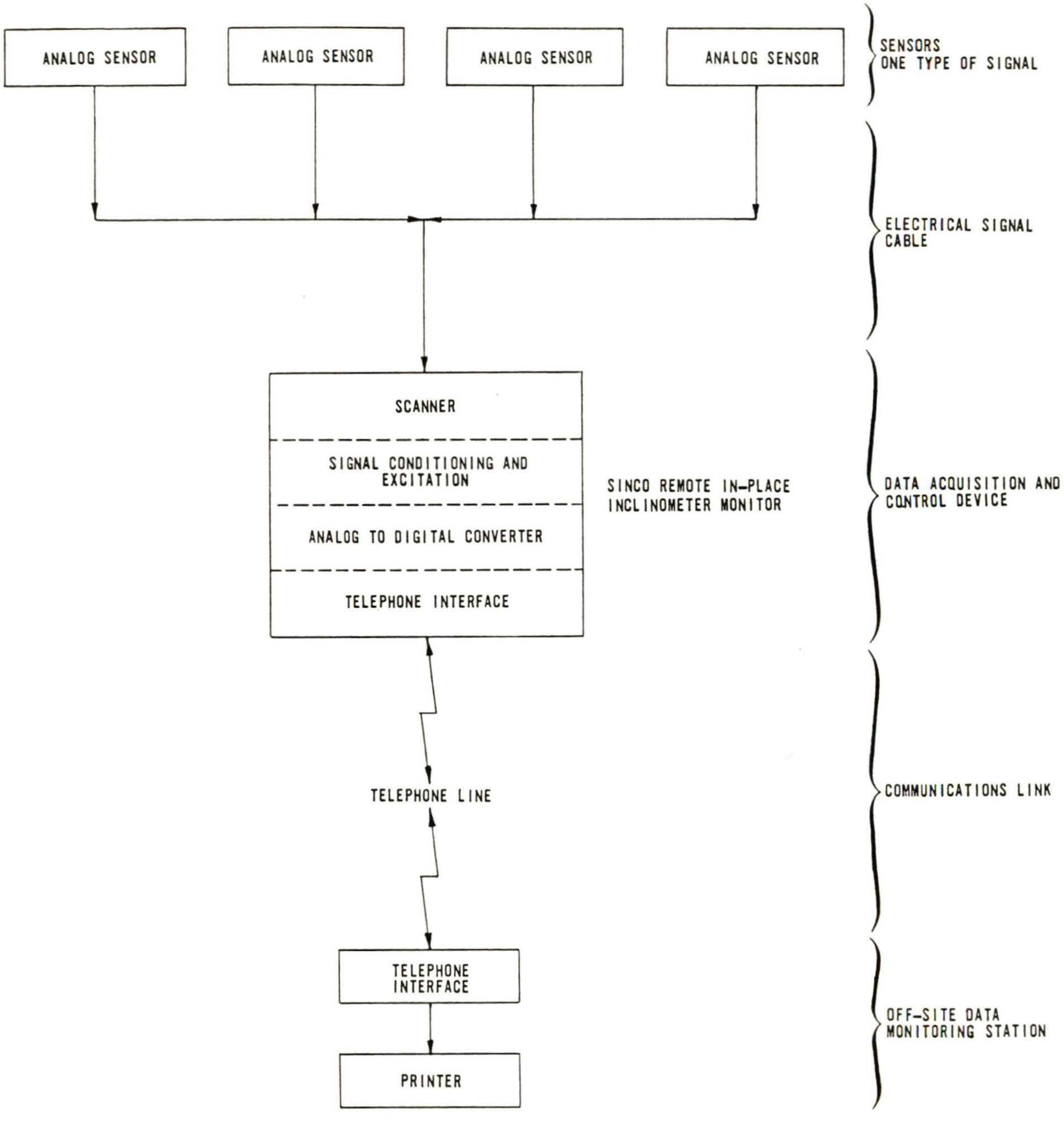


FIG. 3.7 Remote Monitor with Off-Site Data Transmission

Two commercially available systems of this type are the Slope Indicator In-Place Inclinometer Scanner/Remote Monitor and the Irad MA-4 Data Acquisition System. A noteworthy point about these two systems and the first system type discussed, is that they are manufactured by geotechnical sensor manufacturers who provide good interfacing between sensor and monitor. Both types are ruggedly constructed to resist damage commonly in geotechnical field situations.

3.4.3 Interrogatable Remote System with VHF Radio Link

The third system is more complex than the first two, and more useful in remote areas where electric power and telephone links are not available. This system utilizes solar power cells, when 120 VAC is not available, and a VHF radio transceiver to transmit the data to a central receiving station. An example of this type of system is the Bureau of Reclamation's Yakima Hydrological and Meteorological Data Acquisition System shown in Figure 3.8. This system is composed of 18 remote stations and a central receiving station. Each remote station has a capacity of 12 digital sensors, although a maximum of 5 at any one station are used on the present configuration. All of the remote stations are interrogated three times a day by the PDP-11 mini-computer at the central station where the information is collected and some processing occurs. Since the sensors are digital there is no need of an A/D converter at the remote station, which reduces the complexity of the remote station electronics. Existing radio repeaters are used to relay the data to the central station. After reaching the central station the data are retransmitted by telephone lines to the Columbia River Operational Hydromet and Management System (CROHMS) in Portland, and to a CDC Cyber 70 computer at Bureau of Reclamation's Denver Computer Center. This system was designed by EG&G Washington Analytical Services Center under contract with the Bureau of Reclamation. Since EG&G designs turn-key systems, we have limited information on individual portions of the system. Power for the remote stations was either 120 VAC commercial electrical power or by battery. The battery-powered stations will run for a minimum of 180 days without recharging. A major advantage of this system is low energy requirements of the electronics which permit battery or battery-solar panel operation. Some of the disadvantages of the system include: (1) limited expansion in the number of sensors once the system is designed, (2) no printout at the station should the radio fail, and (3) no capability of alerting the central station in the event of an unusual change in one of the parameters being measured.

Another example of this type of system is one developed by the Mining Research Laboratories of Canada Center for Mineral and Energy Technology, which demonstrates several different modes of data transmission within a single system (Figure 3.9). This system differs from some of the others in that no long electrical cables are used to transfer the data; instead, the sensors are all located at one point and the output is transmitted by radio to a base station. From the base station (a mine dispatcher's office) the data are sent by commerical telephone line to the master station for computer processing. Site conditions which require direct radio transmission near a mine are not uncommon. Active mine workings, mine haulage roads, major highways, streams or large topographic changes can make impossible or economically prohibit the use of buried signal cables. Of course, depending on the number and type of cables, there will be a certain distance at which radio transmission becomes more economical simply on the basis of the cost of the cable.

The monitoring system is comprised of digital and analog sensors connected to a borehole extensometer. The output of the analog sensors are multiplexed together and then connected to an A/D converter. The digitized data

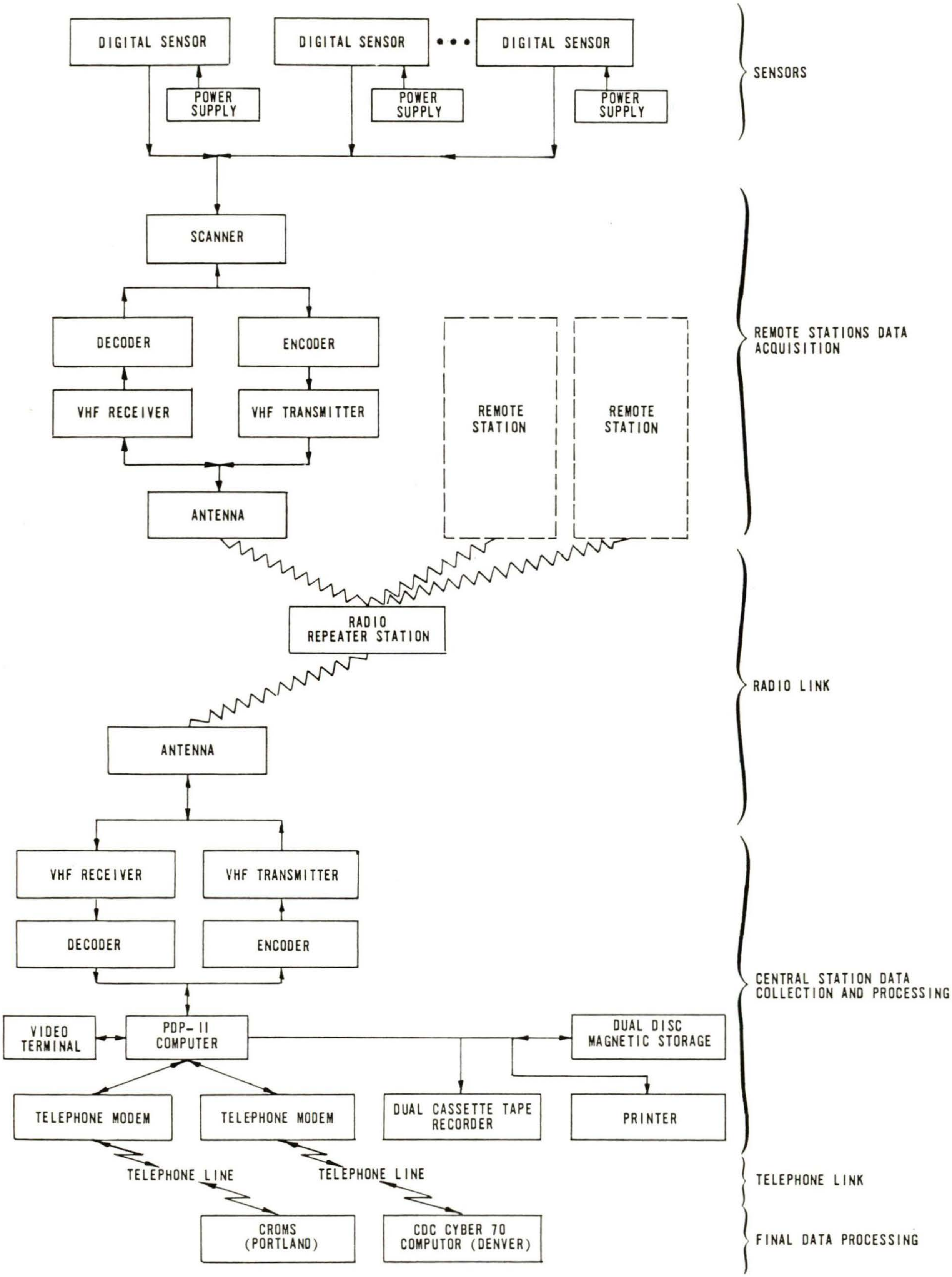


FIG. 3.8 Hydrological Monitoring System using Radio Link and Remote Interrogation

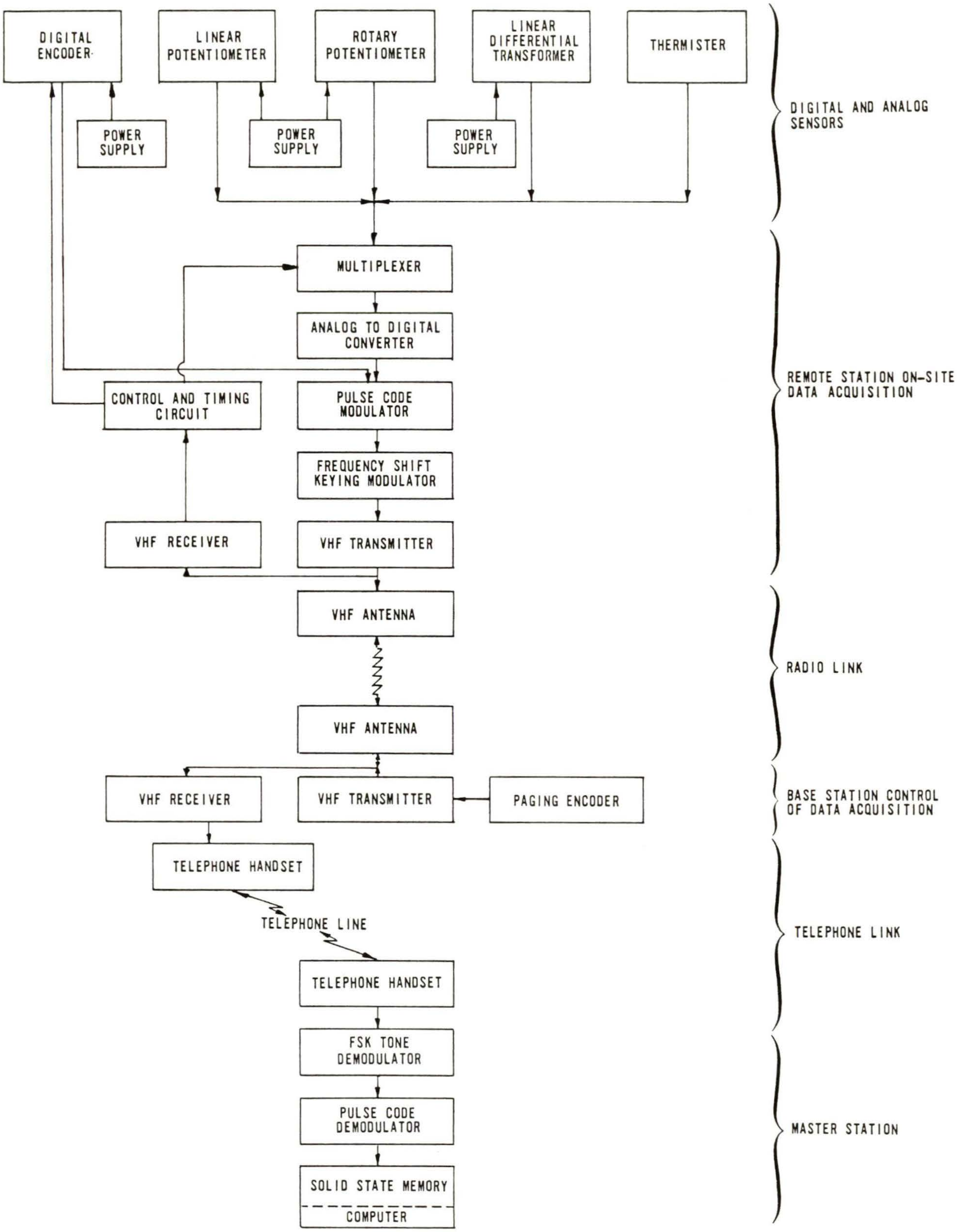


FIG. 3.9 Remote Monitoring System Designed by CANMET for the Jeffery Mine

along with the data from the digital sensors are pulse duration modulated to produce a coded, serial electrical signal. The coded electrical signal is then frequency shift keyed (FSK) and transmitted over a VHF radio link to the base station. The received signal at the base station is coupled to a telephone handset after the master station has been called. At the master station the signal is demodulated and decoded before storing it in a computer. Power for the remote station is provided by Globe gell-cells and power for the heaters was obtained by rechargeable lead-acid cells.

The cost of equipment for the first remote station, not including sensors, was relatively high, approximately $10,000 (1973). Improvements in electronics technology have reduced the number of batteries needed for power and heat, and the cost of the revised remote station was reduced to approximately $5,700 (1974). The system, along with special control circuits, is described in detail by Larocque, 1977.

Advantages of this system include: (1) easy expansion for other remote stations in distant portions of the site at relatively low cost, (2) low power consumption and good response to varying and difficult environmental conditions, and (3) expansion of number and type of sensors at remote stations. Disadvantages of the system include: (1) very limited data processing and no on-site alarm capabilities, (2) interrogation of the remote station is by manual command at the base station, although this could be modified to allow interrogation from the master station, (3) the digital data form used is not a standard ASCII code, and thus requires a special message decoder at the receiving end, and (4) radio transmitters and receivers used in the system conform to Canadian regulations and may not be applicable in the United States.

3.4.4 Remote Interval Timed System Via Satellite Link

The next system to be discussed is a remote, unattended operation which utilizes a satellite relay. One example of this system, which we will describe in detail, is used by the Army Corps of Engineers to monitor river level and other water-related parameters along the Mississippi, Figure 3.10. As of January 1977, this system included 125 remote stations and a single receiving station. Each remote station has up to 12 sensors of mixed analog and digital output and is self-timed to transmit every four hours. Each sensor is measured once an hour and the data are stored in memory until the transmission time. Transmission is by the Geostationary Operational Environmental Satellite (GOES) which receives and relays the data to the National Environmental Satellite Service (NESS) antenna and the Corps' Vicksburg office. The data acquisition, memory and transmitter are all included in a single package manufactured by LaBarge called the Convertable Data Collection Platform (CDCP). The output of the CDCP goes directly to the transmitting antenna. Transmitting power is variable up to 10 watts. Power for the remote station is either 120 VAC commercial power or by batteries recharged by solar cell panels.

The advantages of this type of system are: (1) a large number of remote stations can be handled, (2) the remote stations can be spread out over a very large area, and (3) the equipment is designed for extreme environmental conditions. The major disadvantages of the system include: (1) limited number of sensors (twelve) which can be interfaced without extensive redesign of control and memory circuits, (2) time required to set up an agreement with the government agency in charge of the satellite, (3) interfaces between most types of geotechnical sensors and the CDCP have not as yet been developed, and (4) less flexibility in data acquisition and storage than some other systems. Personnel from the Corps of Engineers have

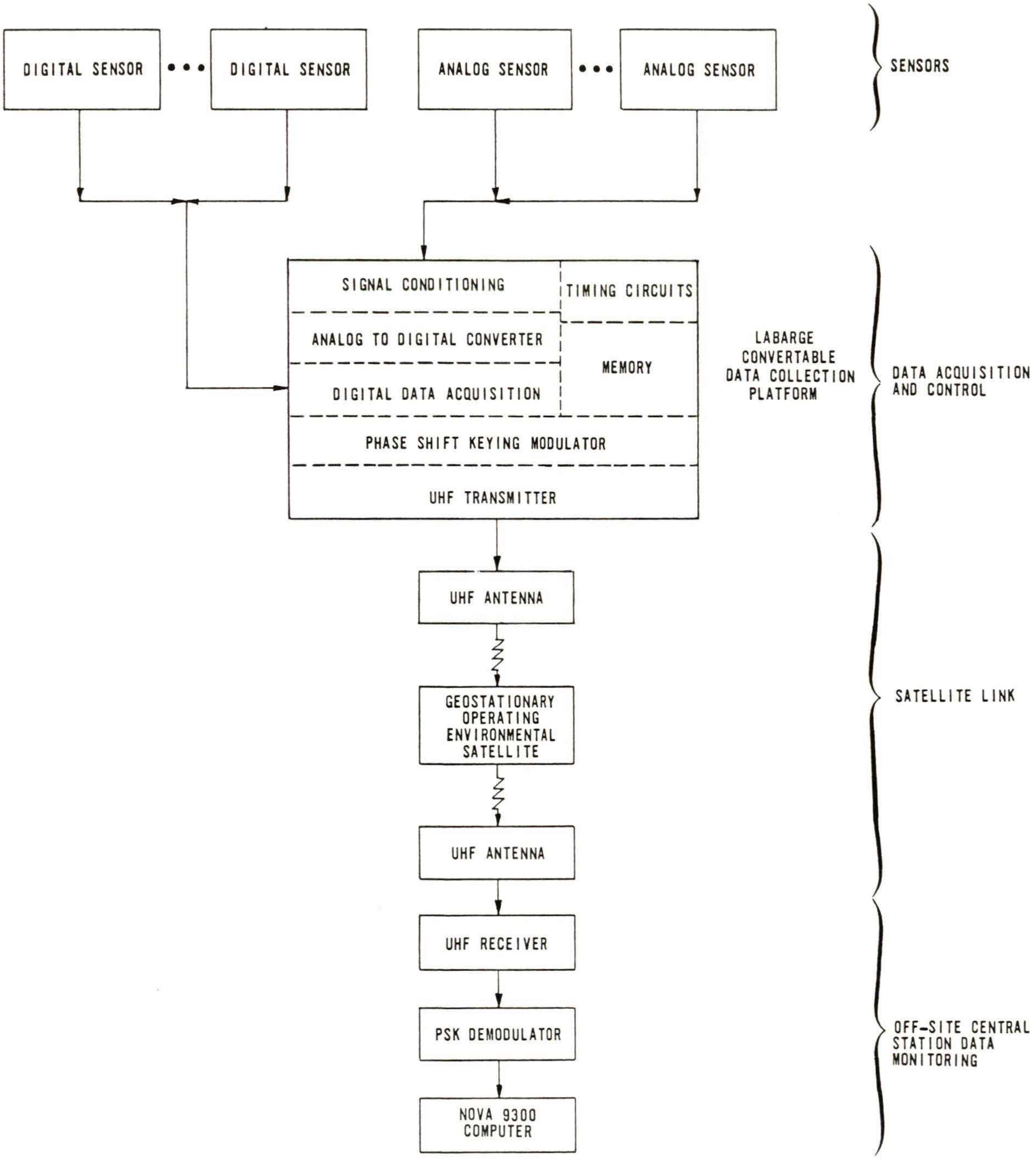


FIG. 3.10 Remote Hydrological Monitoring System using Satellite Communications Link

indicated some problems with both equipment and data transmission, the latter related to output power from the transmitter falling below 10 watts (Belala, 1978). More details of the use of satellites as data relays are presented in Section 3.5.

3.4.5 Data Logger Controlled System

When rapid transmission of data is less important than having capacity for large numbers and types of sensors, then data loggers which have the ability to scan and record many channels of data, become most suitable. Data loggers were developed primarily for laboratory experiments where manual data collection was too slow. As semiconductor circuits became more available and less expensive, the applications for the data loggers have opened up in the industrial fields of quality control and environmental monitoring. More recently, the smaller power requirements of the newer electronics and wide range of environmental conditions under which the logger can perform have encouraged its use in unattended monitoring in the field. An example of a monitoring system using a data logger is shown in Figure 3.11. Such a system has been used by the Bureau of Reclamation to monitor piezometers, inclinometers, extensometers and other sensors near Grand Coulee Dam (Roberts, 1978).

The system at Grand Coulee Dam utilizes sensors linked to the data logger by electrical cables. Power for the sensors is provided by separate circuits along with signal conditioning where necessary. The data logger is programmed to continuously scan all sensors, but to print out only at certain times or when manually requested. The data are recorded on computer compatible magnetic tape which is shipped to a central computer for detailed analysis. Alarm limits can be set for a number of sensors with this type of data logger (Acurex Autodata Nine). If an alarm condition is observed during scanning, the alarm output is activated and an alarm is sounded. This particular system uses two alarm circuits. A local alarm whistle is activated in the building containing the data logger when a limit is exceeded. When the area is unattended for a long period of time, such as a weekend, an alarm condition at the site is transmitted to the dam control room by a telephone line.

One of the advantages of a data logger is the ease and accuracy of data collection when a large number of sensors are involved. Also, scaling of nonlinear sensor output and inclusion of engineering units makes interpretation of the data easier and less time-consuming.

3.4.6 Computer Controlled System

The final system is the most sophisticated in terms of data processing and control. An on-site computer or minicomputer controls the system and takes the place of the data logger. Whenever high speed, real-time sensor measurement and data processing are needed, the on-site computer can provide this service without the need to transfer the data either manually or by radio or telephone. Seismic or acoustic emission signals can require this type of processing. Once the processing is complete, the computer can also activate external devices which can turn sensors off or on.

Disadvantages of a computer controlled system include the time needed to develop software, increased cost and, most important, poor long-term unattended operation. Electrical power interruptions and electrical transients can cause the computer program to shut down, requiring manual operation to restore the system. Recently the functions of a data logger and computer, especially a

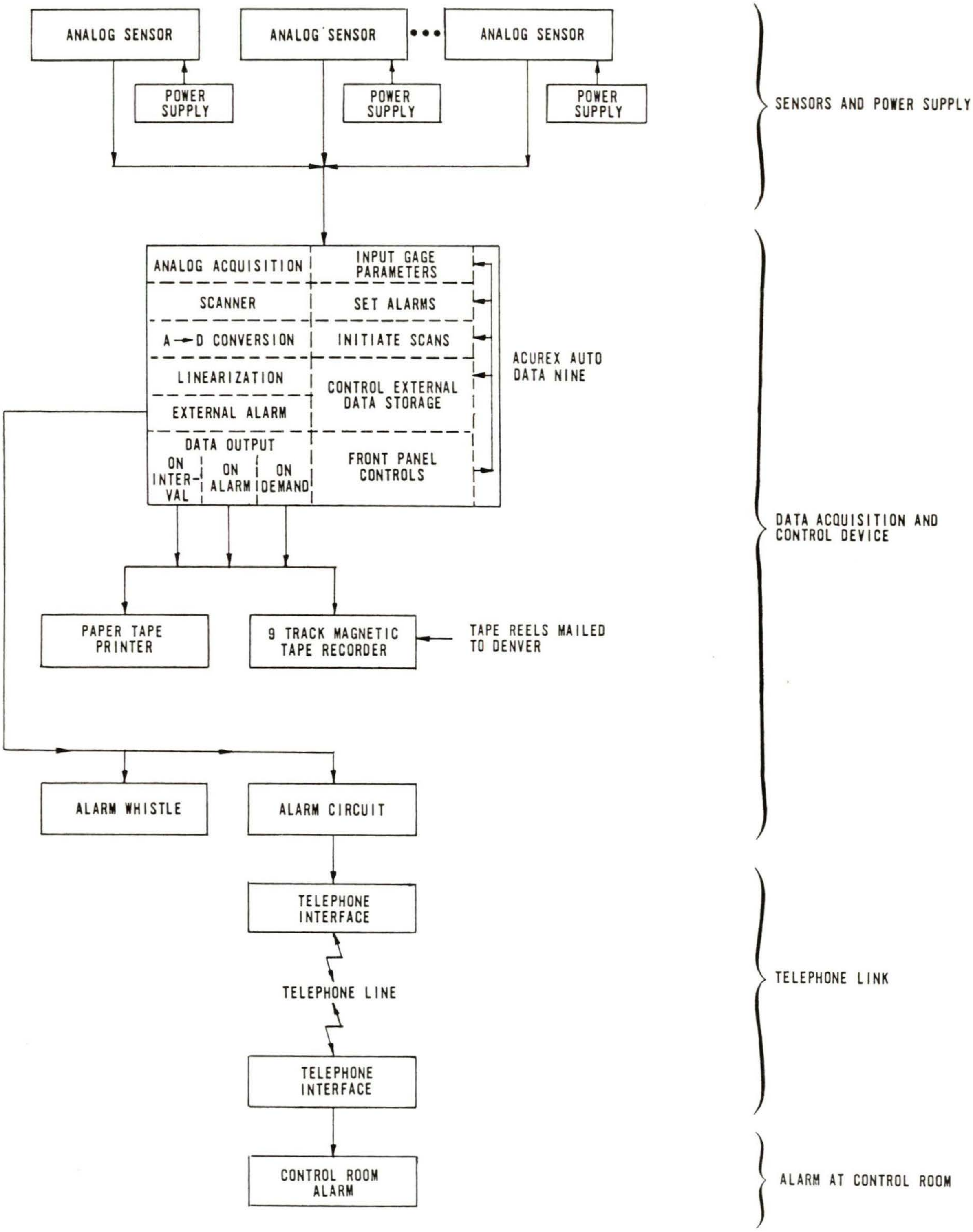


FIG. 3.11 Data Logger Controlled Monitoring System at Grand Coulee Dam

minicomputer, have become increasingly similar, with the minicomputers becoming less sensitive to environmental conditions and the data loggers becoming more sophisticated. Eventually it will probably be impossible to differentiate between them. One example of a minicomputer-controlled system which has been utilized in monitoring coal mine roofs is described by McVey and Serbousek (1976). In this system roof sag, rock bolt load, closure, humidity, and temperature were measured.

Since each system described so far has its own advantages and disadvantages, we have developed a table of attributes important for remote geotechnical monitoring and a qualitative assessment of each system (excellent, good, etc.), with respect to these attributes (Table 3.7). The nature of the assessments are qualitative because of the difficulty in assigning a numerical value to such vaguely defined attributes. The importance of each attribute to a proposed system will depend on both the site conditions and the purpose of installing the system. The table should be used merely to provide a direction for a system designer to pursue. Cost has not been included in the table because it is too dependent on the particular application.

3.5 Data Communication from Remote Sites

3.5.1 General

In the previous section we have referred to the importance of data transmission or communications in an automatic data acquistion system. We will now discuss data transmission in more detail since it is a very important part of automatic data collection and is commonly the weak link in the entire system.

The simplest data transmission occurs when the recorder is attached directly to the sensor as occurs with certain instruments such as flow meters, some types of pressure recorders or certain convergence gages. Some recorders which are attached to borehole collars also have relatively simple data transmission because of the relatively short lead lengths. As more than one borehole or additional instruments are added to the instrumentation system, data transmission becomes more important. Methods of data transmission must be chosen to minimize loss of information and minimize the amount of noise picked up during transmission. However, an increasing variety of available data transmission methods make choosing the recording system much more difficult.

There are many different data transmission methods available for various electrical instruments. The simplest data transmission involves an analog DC voltage which varies in amplitude as a function of increase or decrease in the parameter. Other analog transmission methods include current, frequency, AC voltage or phase. The appropriate analog method usually depends on the particular sensor used; i.e., vibrating wire transducers produce a variation in frequency, but some equipment does exist to modify the output at the sensor before transmitting it to the data collection center. In addition to analog data transmission, digital transmission can be used to transmit data to the collection center. A few available sensors produce a digital signal rather than an analog signal. The electrical methods used in handling digital signals are similar to analog signals, the major difference is in the form of the information. Analog data must be converted at the receiving end through the use of an A/D converter. Digital signals are in discrete packets and signal attenuation and noise are generally less of a problem with digital transmission.

TABLE 3.7

Qualitative Assessment of Various Remote Data Acquisition Systems

System Description	Wide Range of Environmental Conditions	Remote Commumications	Power Requirements	Unattended Operations	Data Processing and Alarms
On-site Recording System	E	N/A	E	E	P
Interrogatable Remote Monitor	G	P to F	G	E	P
Bureau of Reclamation Hydrological Station	G to E	G to E	G to E	E	P
Jeffery Mine System by Canada Centre for Mineral and Energy Technology	G	F to G	G to E	G	P
Remote Interval Timed System (CDCP) Via Satellite Link	G to E	E	F to G	G to E	P
Data Logger Controlled System	F	P to F	F	G	G
Computer Controlled	P	F to G	P to F	P	E

Rating Key:

E	Excellent	P	Poor
G	Good	N/A	Not Available
F	Fair	1	Depends on Individual Manufacturer

TABLE 3.7 (cont.)

Qualitative Assessment of Various Remote Data Acquisition Systems

System Description	Data Storage	Control of Sensor	Number of Sensor	Mixed Sensor Type	Distant Interrogation of System
On-site Recording System	F to G	N/A	G	G	N/A
Interrogatable Remote Monitor	1	N/A	G	F	G
Bureau of Reclamation Hydrological Station	P	P	F	F	G to E
Jeffery Mine System by Canada Center for Mineral and Energy Technology	P to F	G	F to G	G	G
Remote Interval Timed System (CDCP) Via Satellite Link	F to G	F	F to G	G	P to F
Data Logger Controlled System	G to E	G to E	E	G to E	F to G
Computer Controlled	E	E	E	F to G	G

Rating Key:

E - Excellent	P - Poor
G - Good	N/A - Not Available
F - Fair	1 - Depends on Individual Manufacturer

When many sensors are clustered together and are located a significant distance from the data collection station, multiplexing of signals is commonly employed to reduce the cost of electrical cable. Multiplexing generally requires a separate instrument and involves combining several signals together and transmitting them over a smaller number of wires. At the receiving end the signal is demultiplexed by a companion instrument. A good example of multiplexing is the common telephone line in which several conversations are carried simultaneously on a single pair of wires. Multiplexing can be performed with either analog or digital signals and by a variety of methods too complex for this discussion.

So far in the discussion we have utilized electrical cable as the physical medium through which signals are sent. Other mediums, such as VHF and UHF radio transmission, could be used to transmit the data where electrical cable is impractical or uneconomical. Line-of-sight, low power radio transmission is particularly effective in the range of 1,000 feet to 10 miles. Beyond 10 miles, repeater stations are generally required and other long distance communication methods become more practical. In addition, continuous radio transmission requires substantial power.

Most sites have the data collection center near the instruments. The current trend is to minimize the data transmission path length to a data collection center. Sometimes this collection center is not very sophisticated and only converts the data to digital form and then retransmits the information. In other cases, the data location center is much more sophisticated and data processing is performed there. When data processing is performed, the center usually houses a computer and is at least intermittently staffed.

When data from the collection center are sent off-site for more processing, storage or interpretation, two general methods are employed. Either the information is retransmitted electrically or is stored on magnetic media, punched paper tape or printed paper and then shipped. Data which are retransmitted electrically from the collection center are almost universally in a digital format. The three main methods of retransmission are telephone line, microwave with repeaters or by satellite. Only two of these methods were considered appropriate for this project, telephone and satellite, and are discussed in detail in the following sections.

3.5.2 Telephone Transmission

Many methods of telephone data transmission are possible, the choice of which is determined by amount of data, speed of transmission and quality of available telephone lines. Special high quality data lines can be leased for very high speed data transmission but, for most cases, the common dial-up telephone lines are sufficient. The transmission speed over these lines is usually 300 or 1200 baud, which corresponds to approximately 30 or 120 characters per second. Better quality transmission occurs at the lower transmission rate and equipment for transmission at this rate is readily available and relatively inexpensive.

3.5.3 Satellite Transmission

There are several distinct advantages to using a satellite communication link over other data transmission methods, particularly in monitoring geotechnical, environmental, hydrological and meterological parameters. First, these types of measurements are commonly performed in remote areas. Even those measurements performed in accessible areas such as a major electric generating dam, may be far removed from telephone lines or other communication lines. Both the environmental and economic costs of extending hard-wired communication lines can become prohibitive for distances longer than a few thousand feet. A satellite transmitter has the advantage of a fixed cost for anywhere in the U.S. Also, a central data collection center can be set up to collect data from a number of remote stations.

The disadvantages of satellite transmission include: increased amount of time to set up the system, a higher operating cost if only a few stations are involved in the system and additional complex electronic equipment required. Figure 3.12 shows how a simple satellite link performs. Data from sensors is fed to a central collection station which supplies electrical power and signal conditioning for the sensors. The data collection platform or signal conditioning equipment then converts the data to digital form and either stores or transmits the data. Transmission can be either continuous or at selected time intervals, depending on the satellite chosen and the type of measurements. The satellite must be one which has been placed in geostationary orbit so that the transmitter antenna can be fixed in one position. The satellite retransmits the received data to a ground station which decodes the data. From the ground station the data can go directly into a computer for processing or be retransmitted through the telephone lines to another processing center.

There are two types of satellite available for use in relaying ground based data: commercial geostationary satellites and government-operated experimental satellites. The availability of commercial satellites varies depending on demand and the number in orbit. COMSAT and WESTAR are two organizations which currently offer satellite data communication, but the cost of using these satellites is high. The only government research satellite available today for data relaying is the Geostationary Operating Environmental Satellites, GOES, operated by NOAA-NESS. GOES is available to any user as long as the data are made available to other users and the data transmitted are environmental. Permission to use GOES must be obtained from NESS. As a part of this project, we contacted Mr. MacCallum, Chief of Data Collection and Direct Broadcast Branch, NOAA-NESS, describing the present monitoring system and requesting an evaluation of the applicability of using GOES for this project. A copy of our letter along with Mr. MacCallum's reply are included in Appendix B. After review, NESS determined that the project would qualify to use GOES and that a formal request should be submitted by the U.S. Bureau of Mines if a decision was made to utilize these satellites.

After NESS approves a request to use GOES, the particular satellite, GOES-East or GOES-West, most appropriate for the geographical location is chosen and a particular radio frequency and time slot are assigned. Permission to transmit at the assigned frequency must then be obtained from either the Federal Communication Commission (FCC) or Interdepartmental Radio Advisory Committee (IRAC) depending on the particular user. Selection of the Data Collection Platform (DCP) which included the transmitter must be from a list of approved manufacturers. This requirement is to insure that equipment will be sufficiently precise to transmit only at their assigned frequencies, power levels and time intervals. However, the requirement does discourage the development of additional models of DCP and more manufacturers. Details of the timing, power and formating requirements for GOES transmission are covered in detail in NESS 78 (1979) and will not be discussed further here. Most DCP have been designed to have certain selected sensors connected

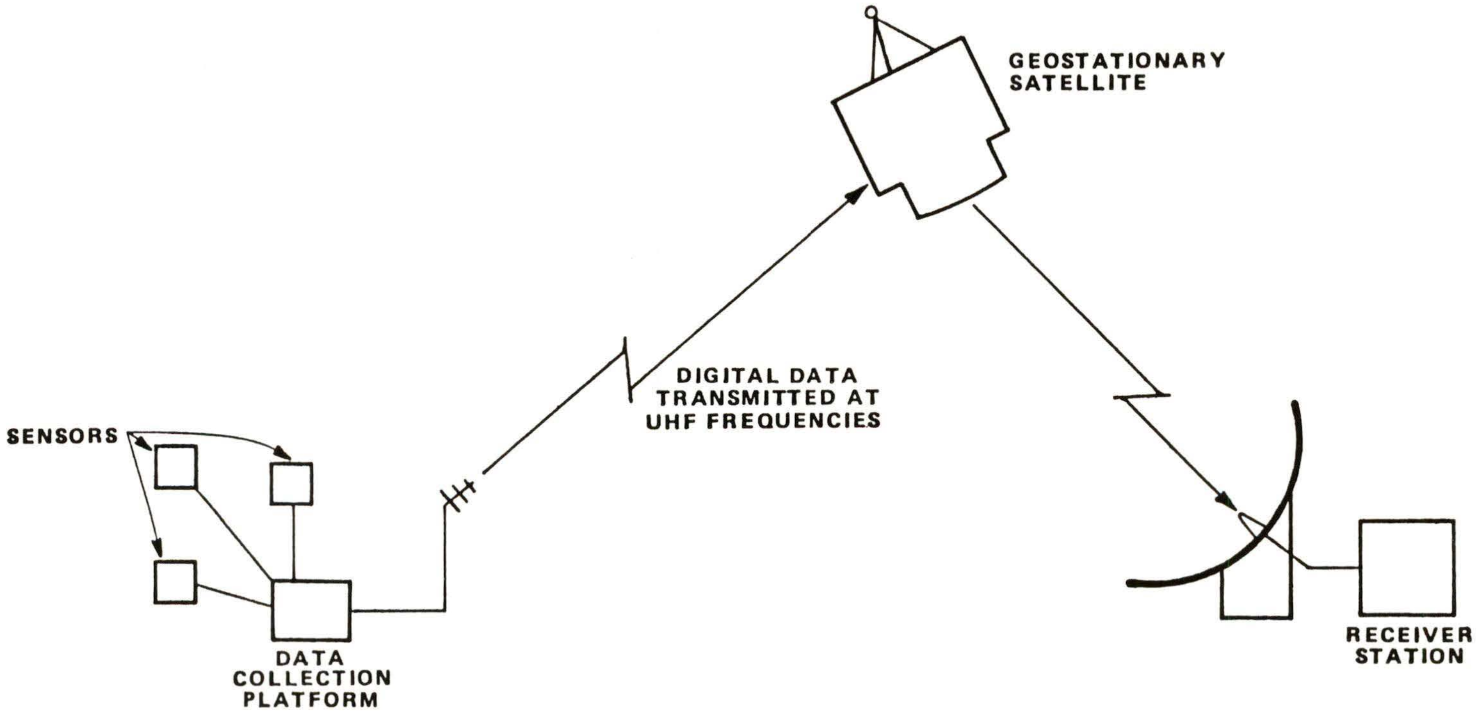


FIG. 3.12 Satellite Communications Link

directly to them. The DCP contains the signal conditioning for these sensors. This particular arrangement is very inflexible and allows only a few sensors to be connected. More important, geotechnical sensors are not generally included in the group of sensors which can be interfaced. A DCP could be designed especially to utilize geotechnical sensors but the current market for such a unit is so small that few manufacturers would likely be interested in investing time and money in development.

The GOES receives data from a number of DCPs and then retransmits this data at a different frequency to ground stations. NESS maintains a ground station which will collect the information and temporarily store it. Access of data from NESS's ground station can be by dedicated telephone link or direct dial-up telephone link. NESS will not process any of the information received but simply relays it as received. Users can construct their own ground station to receive and process their data. Building and maintaining a ground station is very expensive and is usually only justifiable if many DCPs are used or the prompt receipt and processing of data is imperative. As an alternative, there are a few independant companies which maintain their own ground stations which will collect and process data for a number of clients for a fee. This type of service would be very beneficial to a new remote monitoring program utilizing satellite relays because the facilities of a ground station staffed by experienced personnel are available at a time when most of the difficulties will likely be encountered. There is a tremendous advantage in transmitting data directly to a computer in the form of immediate processing and alarm monitoring. Too often on large instrumentation projects where the data are collected manually, a long time passes before the data are even quickly scanned for unusual readings.

4.0 INSTRUMENTATION SYSTEM DESIGNED FOR SELECTED SITE

4.1 Parameters used for Selecting System

The Lower Big Branch impoundment facility is typical of coal waste impoundments in the Eastern Coal Province. The valley is steeply sided and heavily wooded with a thin layer of soil overlying bedrock. The area has a relatively high precipitation rate of approximately 50 inches per year. The precipitation occurs primarily as thundershowers which, when combined with the narrow valley, produce large quantities of water flowing through the valley for short periods of time. The upstream construction method used at this site places good quality material over the top of hydraulically placed fine coal refuse. This fine refuse is much weaker and presents a zone for settlement and movement.

After reviewing all the various parameters that might be measured and the equipment available, we selected the following parameters: vertical displacement, horizontal displacement, surface tilt, seepage, pond level, and meterology. Other parameters such as vertical stress and acoustic emission were considered but rejected due to their perceived limited importance, lack of available instrumentation, or budget constraints.

4.2 System Design and Description

4.2.1 Summary of System

The number and type of instruments selected to measure the above described parameters were chosen by considering the particular configuration and construction of the Montcoal site. Particular models of instruments were chosen to provide reliable data, long-term durability, and precision. However, some parameters were measured with different types of instruments or similar models from different suppliers in order to evaluate their performance.

Vertical deformation was monitored with three multiple position borehole extensometers spread across the embankment width. Each extensometer monitors the settlement of both the fine refuse and top of the coarse refuse (ground surface) which is on top of the fine refuse. Horizontal deformation was measured at 9 levels within the embankment using in-place inclinometers within a borehole. In addition, horizontal deformation was measured manually with a traversing probe inclinometer throughout the embankment thickness.

Pore-water pressure was measured at 7 points throughout the embankment using open standpipe piezometers and with electrical piezometers within the standpipes. The standpipes allowed direct manual readings while the electrical piezometers were incorporated into the automated monitoring. Tilt of the embankment was measured with 3 servo-accelerometer-type tiltmeters mounted at the ground surface and spread out across the embankment width.

To measure seepage at one point on the embankment slope a weir with a remote monitoring station was constructed. The level of impounded water behind the embankment was monitored with a specially designed pond level sensor. Three meteorological parameters, temperature, rainfall, and barometric pressure were measured to permit correction of geotechnical data caused by changing environmental conditions.

Data from all automatically monitored instruments were transmitted via buried electrical cables to a data collection center located in a trailer adjacent to the embankment. A data logger monitoring system was chosen to automatically measure the instruments. The data logger and associated signal conditioning equipment was kept in the trailer. Power and telephone lines were brought to the trailer to provide electrical power for heating and logging equipment as well as provide remote access to the system. Data collected at the site were periodically transmitted by telephone to our Seattle office for computer processing and storage.

4.2.2 System Design

4.2.2.1 Selected Instruments

Locations of the instruments and the data collection station are shown on the site plan (Figure 4.1) of the impoundment structure along with pertinent physiographic features. Cross section X-X' (Figure 4.2), shows the elevation and positions of the standpipe piezometers in the embankment at the time we began installing instruments for this project. The top of the embankment had a maximum elevation of 1125 feet at that time and construction to raise the embankment was in progress. Figure 4.3 shows cross section X-X' at the end of the project with the embankment elevation of 1175 feet, and also shows the location of the instruments installed during this project. Figures 4.4 and 4.5 show section Y-Y' in plan and elevation after the new instruments had been installed, and shows the locations and elevations of the instruments installed along the 1120-foot bench.

The majority of the instruments are located along the 1120-foot elevation bench which was the embankment crest in 1978. A few piezometers, the seepage monitoring device and the pond level sensor, are located along the embankment sides. Drawings and stability analysis developed by D'Appolonia, Inc. for this site have been studied so that the instruments are located to intersect as many potential failure surfaces in the embankment as economically feasible. Table 4.1 lists the various instruments and their respective boreholes. Detailed discussion of the instruments follows.

Vertical deformation is measured with three multiple-position borehole extensometers (MPBX). These instruments consist of 1) a hydraulically expandable anchor, 2) a sleeved stainless steel rod for transmitting anchor movement, 3) a reference head containing the electrical displacement transducer, and 4) a portable mechanical readout device. The extensometers are shown on Figure 3.1 and were supplied by the Slope Indicator Co.

The hydraulic anchors (Borros Point) consist of three steel prongs which are forced out to a diameter of approximately 12 inches. Stainless steel rods threaded to the anchors transmit anchor movements to the reference head. The rods are ¼-inch OD, 10 feet long, flush-coupled and protected inside ¼-inch rigid PVC pipe. The reference head is shown on Figure 3.1 and can accommodate up to five electrical linear potentiometers with a four inch range. The reference head is designed such that rod displacements can be measured with the electrical sensors for remote monitoring or manually with a depth micrometer for direct reading and calibration.

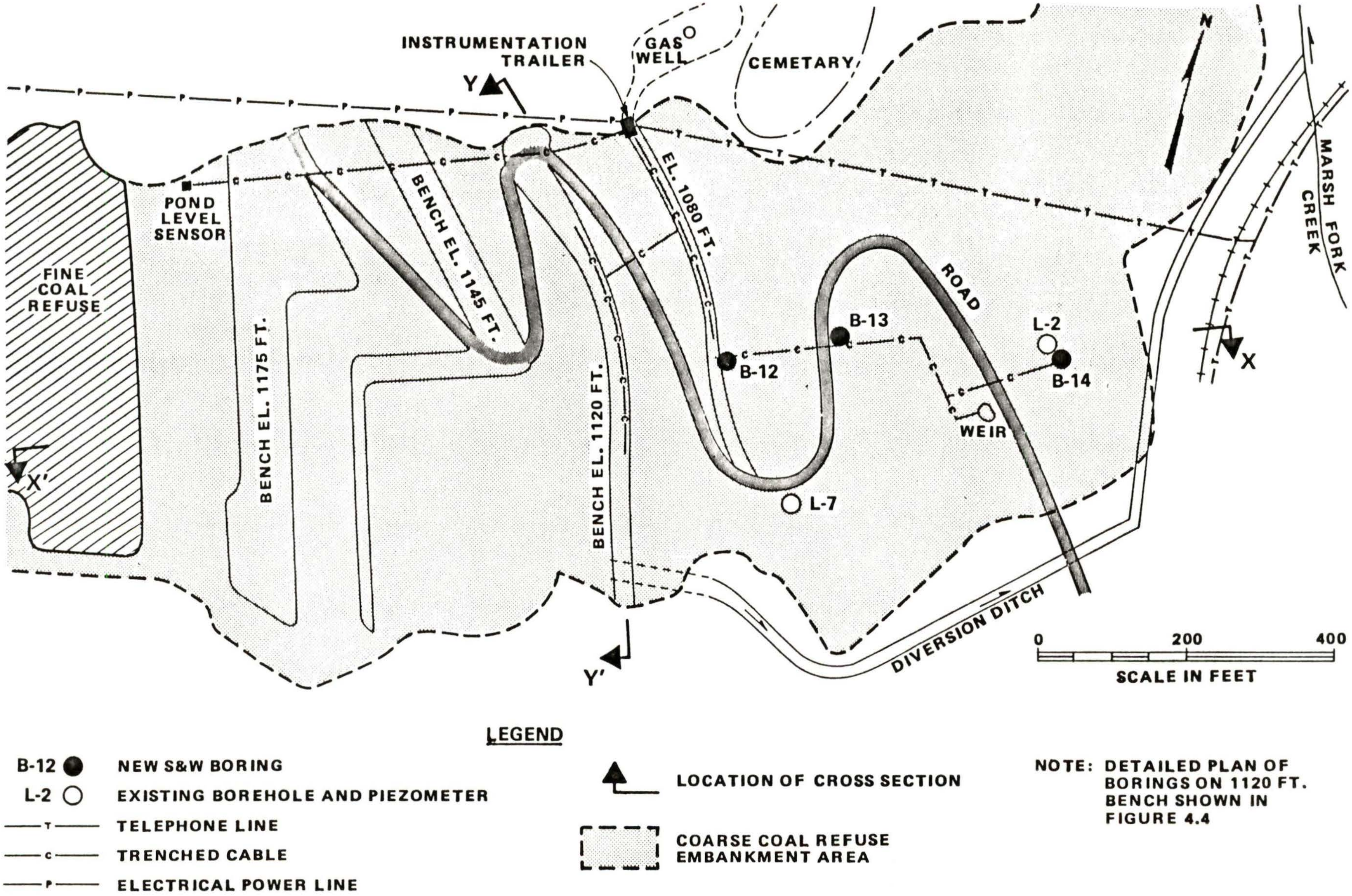
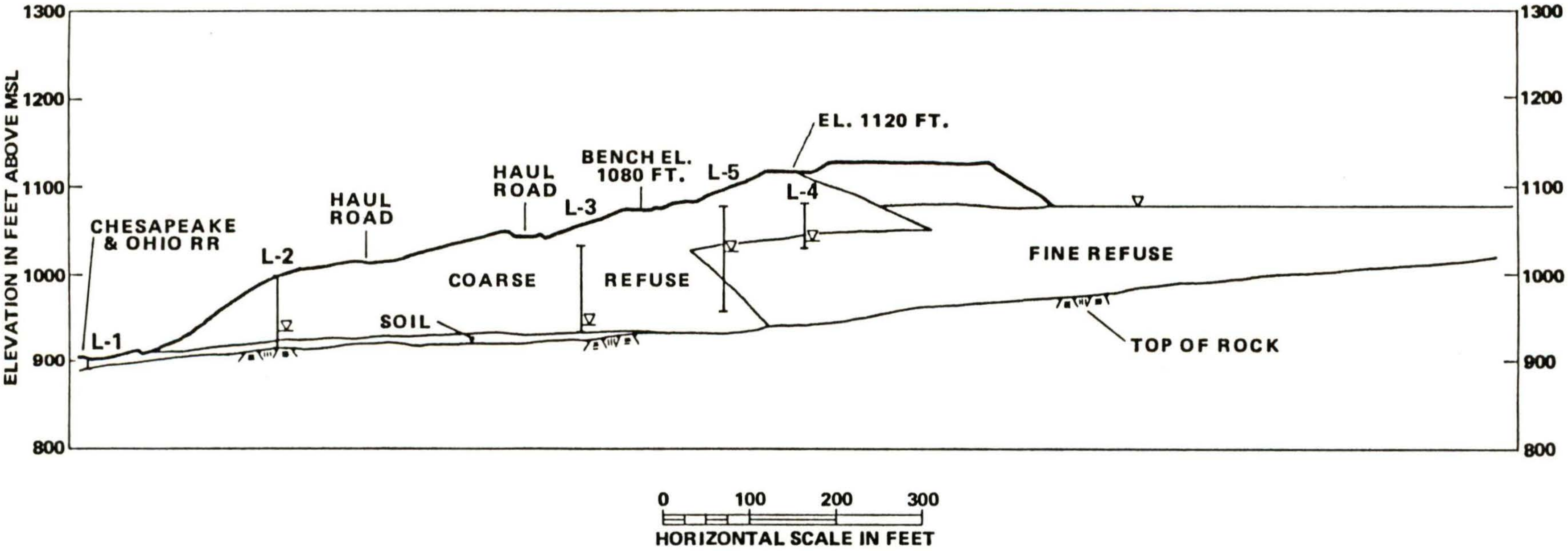


FIG. 4.1 Lower Big Branch Impoundment Site Plan



LEGEND

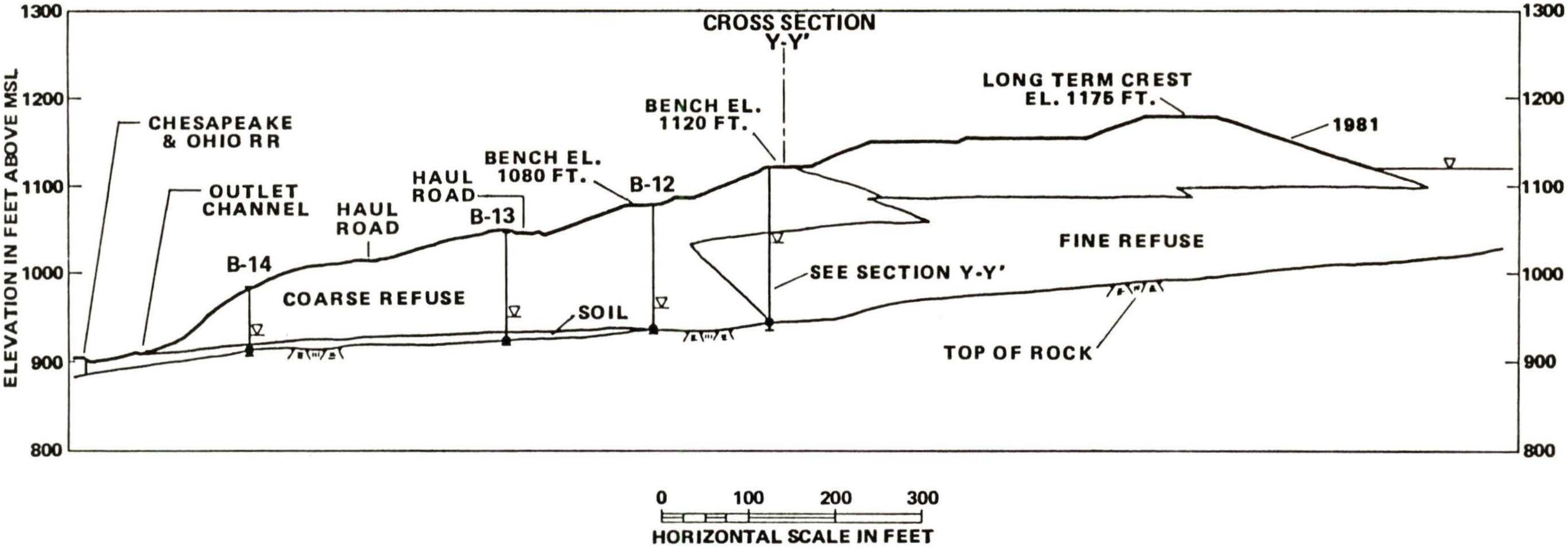
L-1 EXISTING STANDPIPE PIEZOMETER WITH WATER LEVEL AS SHOWN

MSL MEAN SEA LEVEL

NOTE: 1) DERIVED IN PART FROM 1978 D'APPOLONIA REPORT ENTITLED, 'MODIFICATION TO EXISTING COAL REFUSE DISPOSAL FACILITY, LOWER BIG BRANCH, MONTCOAL, WEST VIRGINIA.'

2) ALL SUBSURFACE BOUNDARIES ARE APPROXIMATE.

FIG. 4.2 Cross-Section X-X' Prior to Installing Instruments



LEGEND

B-12

NEW STANDPIPE PIEZOMETER WITH WATER LEVEL AS SHOWN

LOCATION OF ELECTRICAL TRANSDUCER

MSL MEAN SEA LEVEL

NOTE: 1) DERIVED IN PART FROM 1978 D'APPOLONIA REPORT ENTITLED, 'MODIFICATION TO EXISTING COAL REFUSE DISPOSAL FACILITY, LOWER BIG BRANCH, MONTCOAL, WEST VIRGINIA.'

2) ALL SUBSURFACE BOUNDARIES ARE APPROXIMATE.

3) SHANNON & WILSON BOREHOLES ONLY SHOWN FOR CLARITY.

FIG. 4.3 Cross-Section X-X' of Coal Impoundment at End of Project

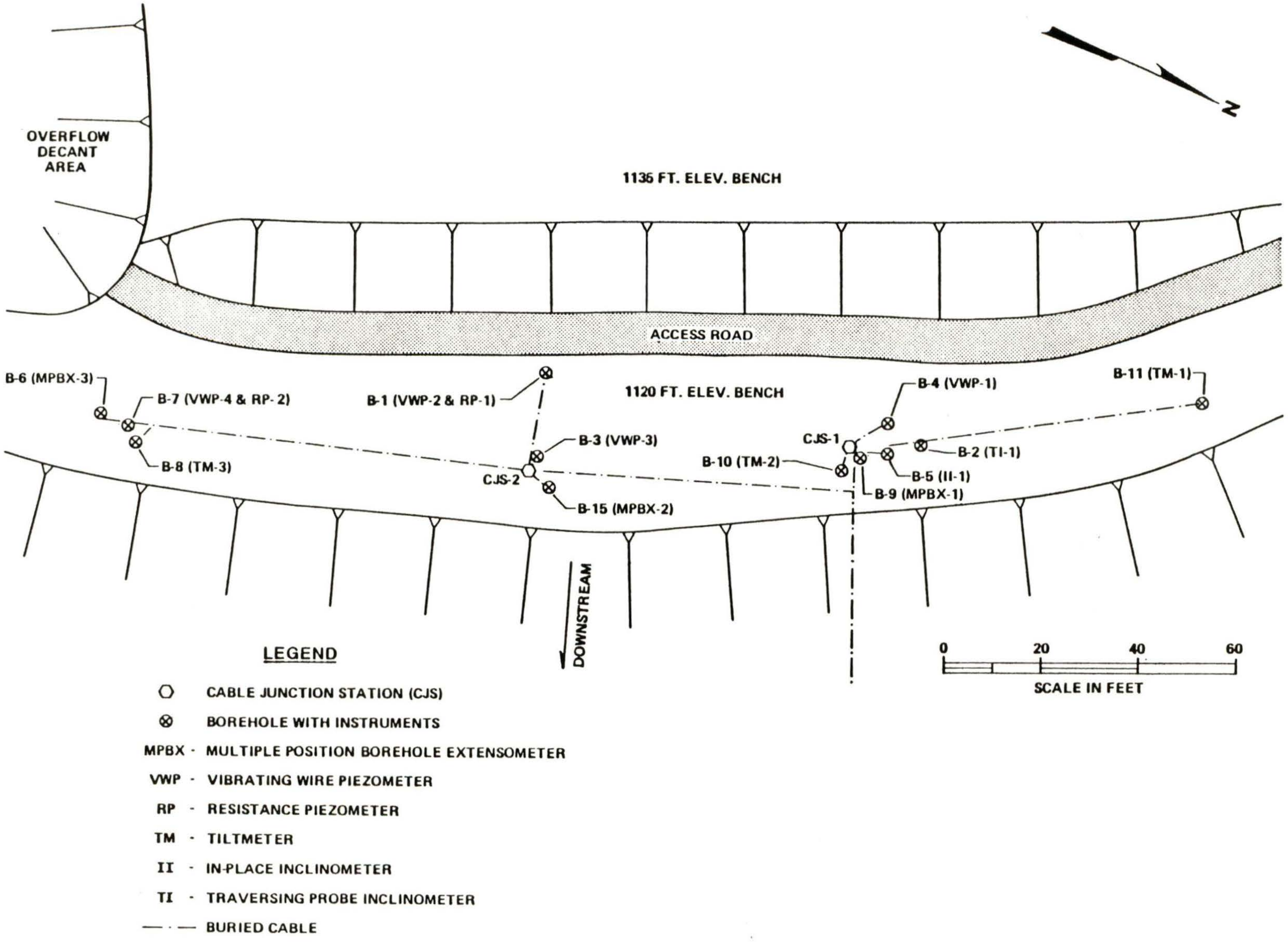
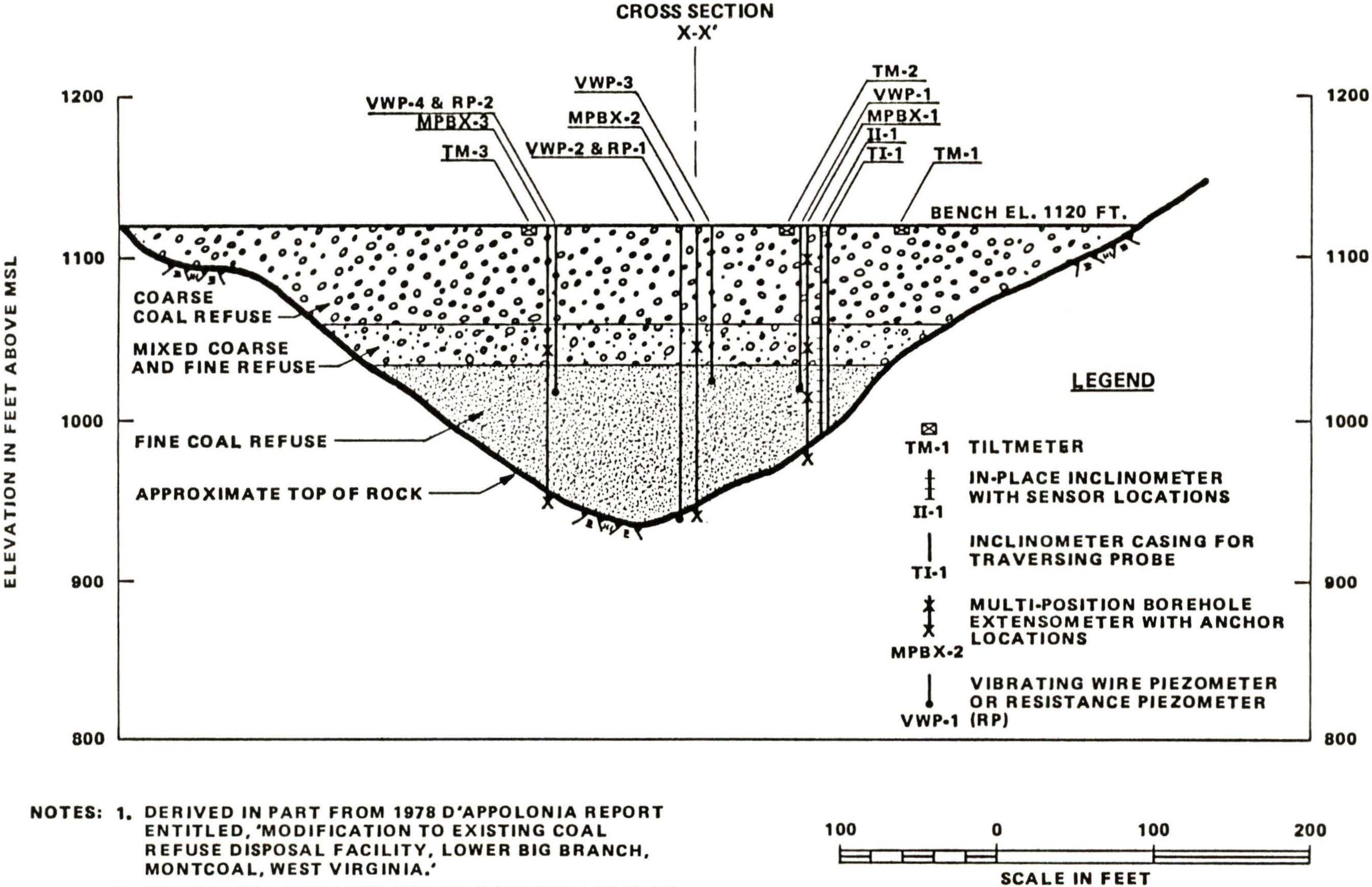


FIG. 4.4 Plan of Section Y-Y'



NOTES:
1. DERIVED IN PART FROM 1978 D'APPOLONIA REPORT ENTITLED, 'MODIFICATION TO EXISTING COAL REFUSE DISPOSAL FACILITY, LOWER BIG BRANCH, MONTCOAL, WEST VIRGINIA.'
2. HORIZONTAL DISTANCE BETWEEN BOREHOLES IS APPROXIMATE, SEE FIG. 4.4 FOR ACTUAL DISTANCES.

FIG. 4.5 Cross-Section Y-Y'

TABLE 4.1

List of Sensors and Locations

Sensor	Manufacturer	Model No.	Sensor No.	Serial No.	Borehole Location	Elevation (Depth in feet)
Vibrating Wire Piezometer	Irad Gage Co.	PW-100	VWP-1	14-2	B-4	1015.2 (104.6)
			VWP-2	14-7	B-1	943.8 (175.7)
			VWP-3	14-6	B-3	1002.7 (117.0)
			VWP-4	14-9	B-7	1015.0 (104.0)
			VWP-5	14-3	B-12	942.8 (139.0)
			VWP-6	14-8	B-13	930.5 (125.7)
			VWP-7	14-1	B-14	920.0 (73.2)
Electrical Resistance Piezometer	Slope Indicator	P/N 56442	RP-1	41107	B-1	942.7 (176.9)
			RP-2	41109	B-7	1013.8 (105.2)
Biaxial Tiltmeter	Terra Technology	85-2032	TM-1(A)	101	B-11	1118.0 (2)
			TM-1(B)	101	B-11	1118.0 (2)
			TM-2(A)	102	B-10	1119.3 (2)
			TM-2(B)	102	B-10	1119.3 (2)

TABLE 4.1 (cont.)

List of Sensors and Locations

Sensor	Manufacturer	Model No.	Sensor No.	Serial No.	Borehole Location	Elevation (Depth in feet)
Biaxial Tiltmeter	Slope Indicator	P/N 50327-1	TM-3(A)		B-8	1118.8 (2)
			TM-3(B)		B-8	1118.8 (2)
Electrical Resistance Piezometer	Slope Indicator	P/N56442	PLS	41108	See Site Plan	≃1105
Fluid Level Monitoring Device	Leupold & Stevens	A-71	Weir	98172	See Site Plan	—
Pressure Transducer	Setra	250	Barometer	24174	At Instrument Trailer	≃1085
Multiple Position Borehole Extensometer	Slope Indicator	51891	MBPX-1(1)	L.P.1	B-9	978.8 (140.7)
			MPBX-1(2)	L.P.3	B-9	1010.5 (109.0)
			MPBX-1(3)	L.P.4	B-9	1044.9 (74.6)
			MPBX-1(4)	L.P.5	B-9	1098.5 (21.0)
			MPBX-2(1)	L.P.7	B-15	942.9 (176.3)
			MPBX-2(2)	L.P.6	B-15	1042.6 (76.6)
			MPBX-3(1)	L.P.10	B-6	946.7 (171.5)
			MPBX-3(2)	L.P.8	B-6	1043.7 (74.5)

TABLE 4.1 (cont.)

List of Sensors and Locations

Sensor	Manufacturer	Model No.	Sensor No.	Serial No.	Borehole Location	Elevation (Depth in feet)
Thermo-couple	Pyrometric Service	Type "T" Thermocouple	Thermo-couple 1	— —	At Instrument Trailer	—
			Thermo-couple 2	—	At Instrument Trailer	—
Uniaxial In-Place Inclinometer	Slope Indicator	P/N50432	II-1	021	B-5	985.1 (134.2)
			II-2	020	B-5	993.1 (126.2)
			II-3	022	B-5	1001.1 (112.2)
			II-4	019	B-5	1009.1 (110.2)
			II-5	017	B-5	1017.1 (102.2)
			II-6	016	B-5	1025.1 (94.2)
			II-7	018	B-5	1033.1 (86.2)
			II-8	015	B-5	1041.1 (78.2)
Rain Monitor	Leupold & Stevens	A-71		91871	At Instrument Trailer	—

The MPBXs were placed at three locations along the 1120-foot bench as shown in Figures 4.4 and 4.5. All three units have anchors placed in stable bedrock so that deformations along the borehole can be referenced to a stable point. Use of a stable reference point allows measurement of the reference head settlements and, consequently, surface settlements. MPBX-2 and MPBX-3 have additional anchors at a depth of approximately 75 feet at the base of the coarse coal refuse to determine settlements within the fine coal refuse. MPBX-1 has a total of four anchors, one in the bedrock, one in the middle of the fine coal refuse, one at the base of the coarse refuse, and one in the middle of the coarse refuse. The uppermost anchor is particularly valuable for isolating deformation related to frost heave and minor surface disturbances from the deep-seated deformations due to settlement or instability. The MPBXs are spaced out across the 1120-foot bench to measure differential deformations in this area of the embankment.

Subsurface deformations are measured with an in-place inclinometer installation (II-1). The in-place inclinometer installation, as shown on Figure 4.6, consists of 1) ABS plastic inclinometer casing joined in 10-foot lengths by cemented couplings and installed in a borehole, 2) eight in-place, uniaxial servo-accelerometer sensor units, 3) electrical cabling to connect the sensors to the ground surface, and 4) a junction box. A second casing was installed about 5 feet away in which a portable probe inclinometer can be lowered periodically to manually check deformations measured by the in-place inclinometer sensors. The casing, sensors, cable, and associated hardware was supplied by the Slope Indicator Co.

The 2.75-inch O.D. casing sections contain four longitudinal grooves spaced equidistant around the inside of the casing. The grooves are used to guide pairs of spring-loaded wheels attached to the sensors and, thereby, orient and center the sensors within the casing. The ABS plastic casing is resistant to corrosion and should survive many years burial in the embankment.

The sensor elements are a servo-accelerometer capable of monitoring horizontal deflections to within approximately 0.01 inch over the 8-foot vertical gage length. Since deformations are anticipated to be primarily transverse to the embankment crest, uniaxial sensors were chosen to minimize cost. A pair of stainless steel wheels are attached to the base of each sensor to guide the sensors down the casing. The wheels, one fixed and the other spring-loaded, also serve to center the sensors in the hole to allow maximum casing deflection before casing distortion interferes with free movement of the gage. A length of stainless steel tubing is rigidly attached to the top of each sensor which, together with the sensor, defines the gage length of the instrument. At this site, a gage length of 8 feet was selected to distribute the 8 sensors over the lower 64 feet of the hole where the deformation was anticipated to be greatest. Each instrument, sensor plus 8-foot tubing, are interconnected by a universal joint to allow independent movement of each instrument. The deepest sensor is placed in bedrock to provide a stable reference point. Above the fine coal refuse, stainless steel tubing without sensors was placed to connect the instrument to ground surface. Each sensor is individually wired to the junction box at the top of the hole with 6-conductor, #20 AWG, shielded, polyethylene-jacketed electrical cable.

Pore-water pressures were measured using several types of piezometers. Each piezometer installation consisted of: 1) a 2-inch PVC open standpipe casing, 2) an electrical sensor to monitor water level in the casing, 3) an electrical cable to connect the sensor to ground surface, and 4) a protective steel cover to prevent damage from construction equipment (see Figure 4.7).

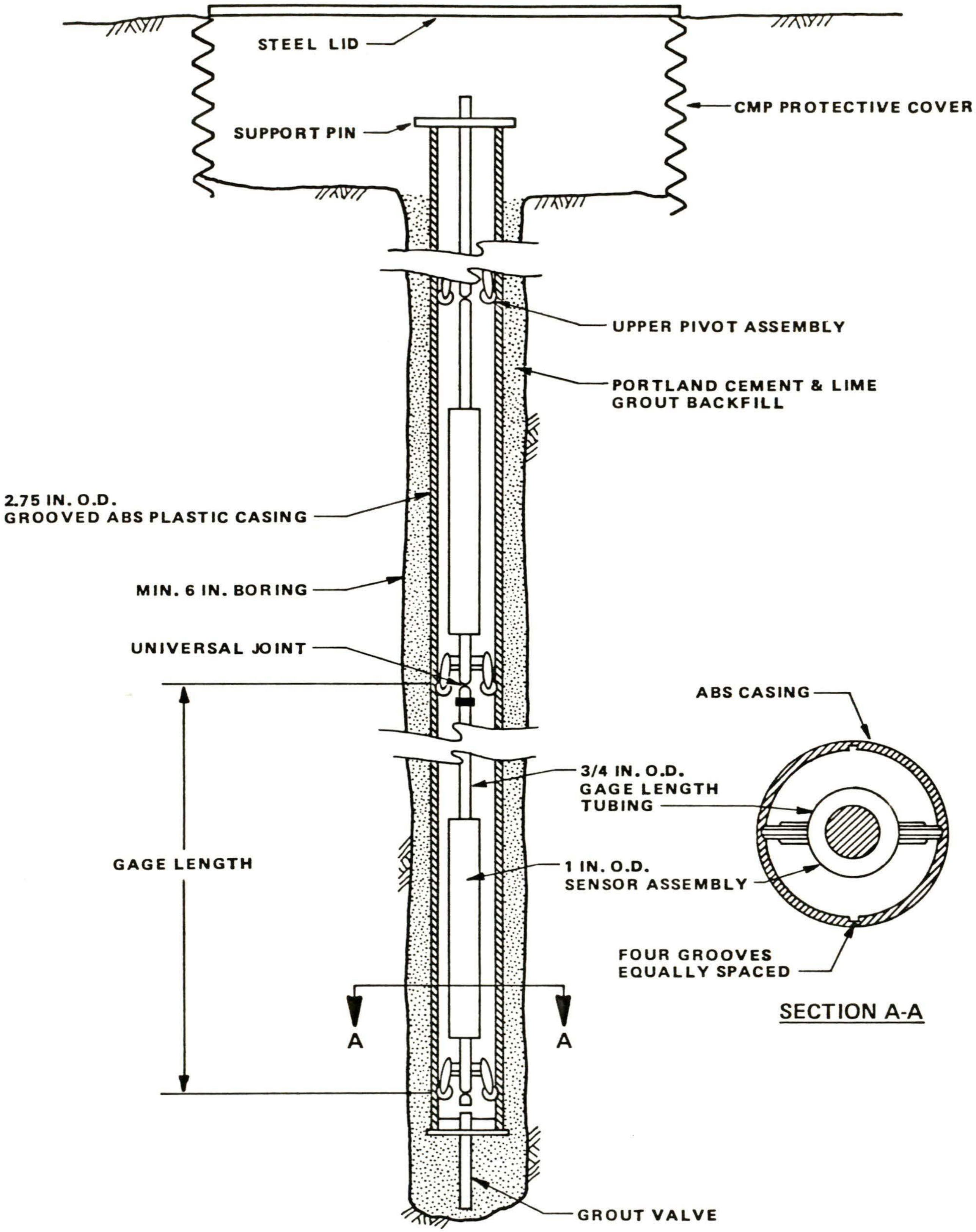


FIG. 4.6 In-Place Inclinometer Installation

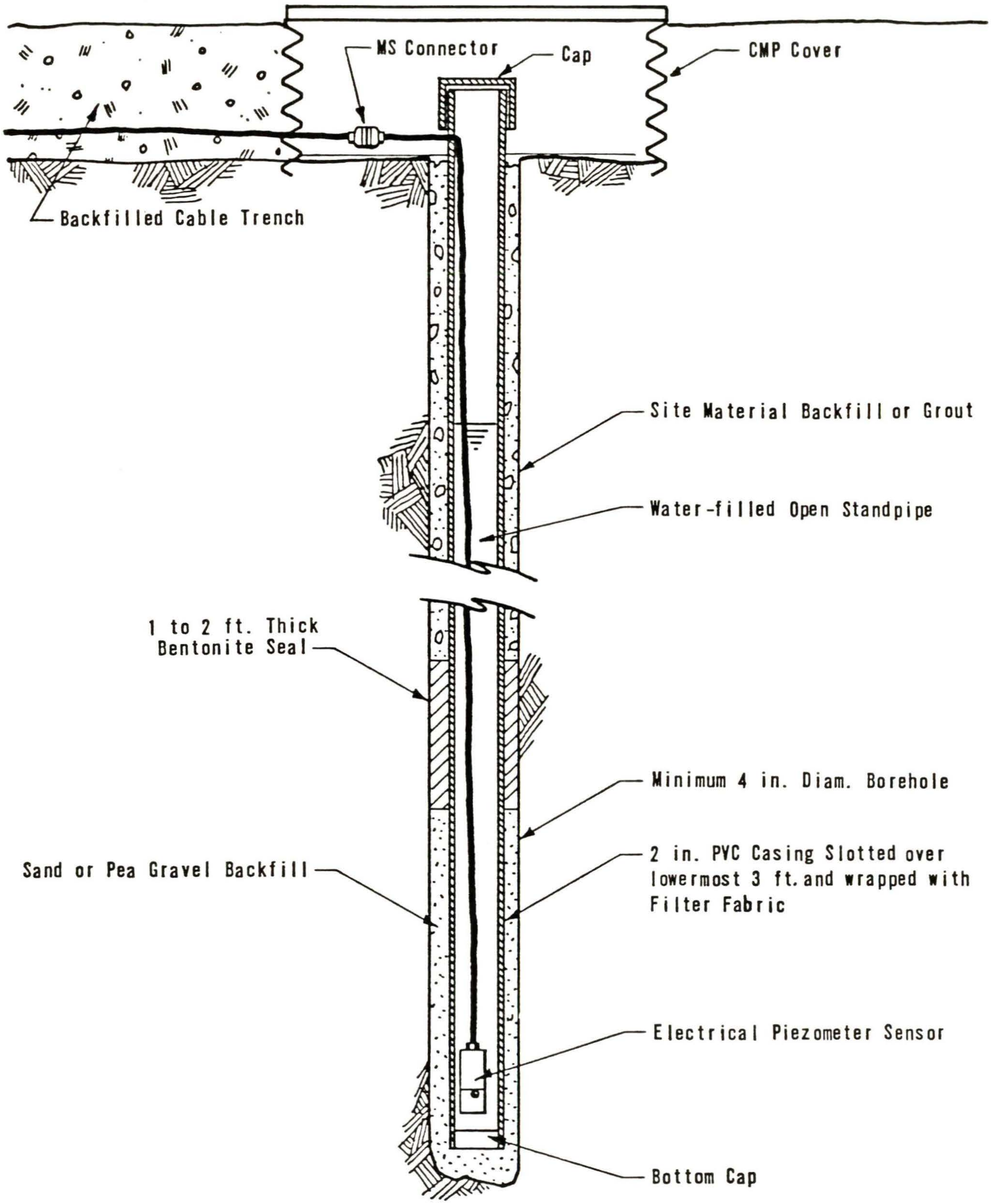


FIG. 4.7 Piezometer Installation

Two types of electrical piezometer sensors were installed in various borings along the 1120-foot bench and along the embankment downstream slope. The first, a vibrating wire piezometer (VWP), was suspended in seven standpipe wells. Four of these wells are located along the 1120-foot bench, and the remaining three are spaced along the downstream slope in the center of the valley, as shown on Figure 4.3. Locations were selected to define the piezometric surface in the fine refuse and surficial soil remaining between the base of the embankment and bedrock. These locations should provide information to monitor pore-water pressure changes.

The VWP uses the vibrating wire principal, discussed in Section 3.2.4, to measure the deflection of a steel membrane caused by external water pressure. The piezometers used at this site had a pressure range of 0-100 psi (absolute) and were manufactured by the Irad Gage Co. The 1-5/16-inch by 5-inch long sensors, shown on Figure 3.5, were electrically connected to the surface with a 2-conductor, #20 AWG, shielded, rubber-jacketed electrical cable.

The other type of electrical piezometer used at this site was a resistance piezometer (RP). These piezometers were supplied by the Slope Indicator Co., and utilized full Wheatstone bridge electrical sensors. These record electrical resistance changes as the external water pressure changes, as described in Section 3.2.4. Two sensor models were used in the two resistance piezometers. One sensor, manufactured by Senso-Metric, Inc., employs semiconductor resistance bridges bonded to a steel diaphragm. The second sensor (CEC-1000) was manufactured by Bell & Howell, and this sensor has a semiconductor resistance bridge sintered to a stainless steel diaphragm. Both sensors were packaged for use as piezometers by Slope Indicator Co. in plastic bodies with a Norton stone filter. The major difference in these two sensors was the manufacturing techniques. The CEC-1000 was supposed to have excellent long-term drift characteristics.

The two resistance piezometers were placed in the same standpipes as two VWPs as a check on the accuracy of the VWPs. Both installations were on the 1120-foot bench, see Figures 4.4 and 4.5; one in a deep borehole to bedrock, and the other in a shallower casing.

Surface tilt was measured at this site with three tiltmeters located along the 1120-foot bench. Each installation consisted of: 1) a biaxial tilt sensing unit, 2) a stand for the tiltmeter, 3) an electrical cable and connections, and 4) a protective cover (Figure 4.8).

Two models of tiltmeter were employed at this site, both models being servo-accelerometer-types. The first, TM-1 and TM-2, were manufactured by Terra Technology, Inc., and the third (TM-3) by Slope Indicator Co. The two different models were selected to assess the durability and accuracy of each. The two sensors in each instrument are aligned at right angles to each other with sensors aligned along both horizontal axes of the embankment. The instrument stands consisted of 2-inch steel pipe concreted into the embankment surface.

The level of the water impounded behind the embankment was monitored with a pond level sensor developed for this purpose. To our knowledge, no satisfactory commercial instrument is available for remotely monitoring the changing level of saturated fine soil and water in a waste impoundment such as at Montcoal. Consequently, the pond level sensor was designed around available components (see Figure 4.9). A 6-inch diameter corrugated,

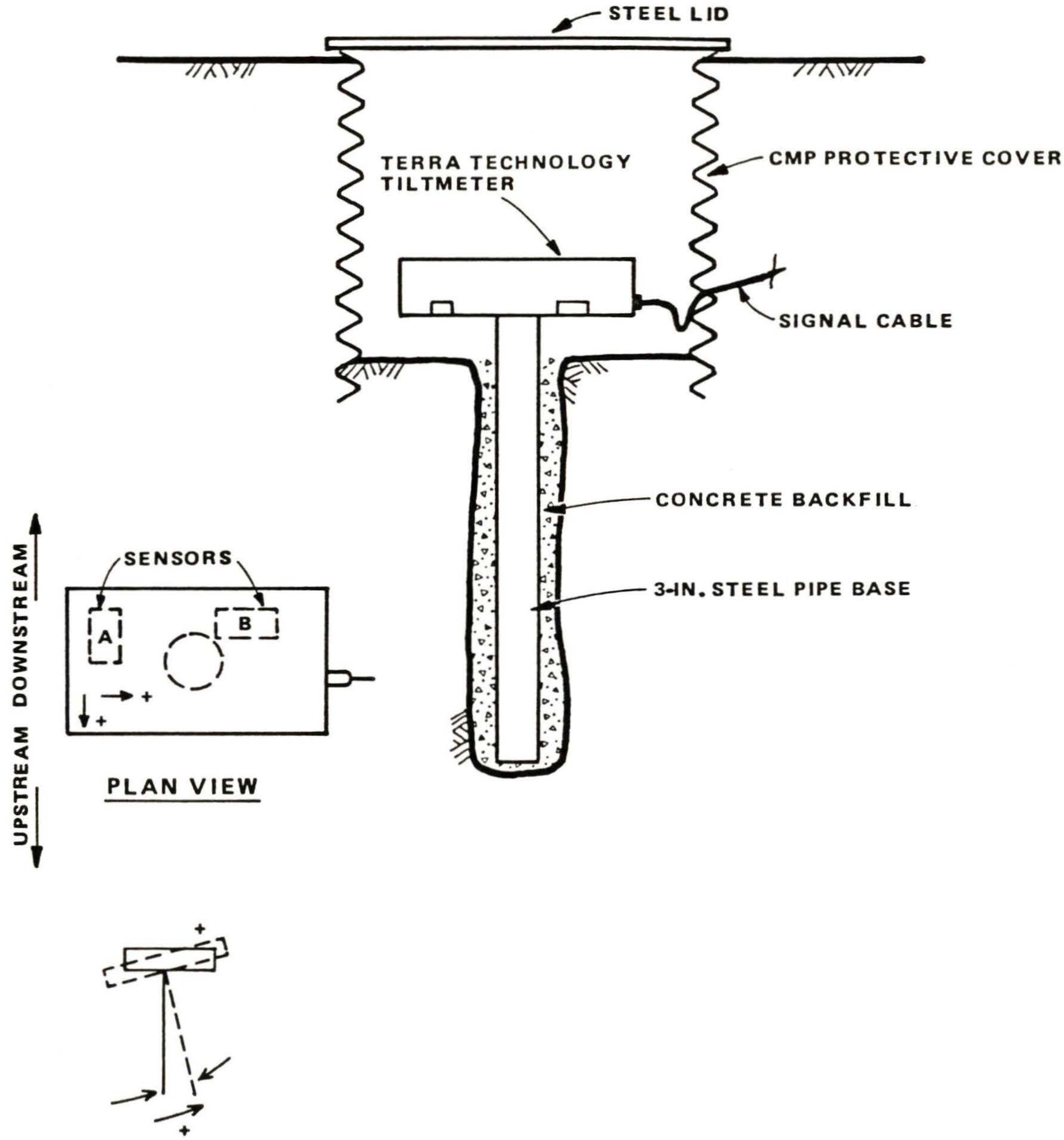


FIG. 4.8 Tiltmeter Installation and Orientation

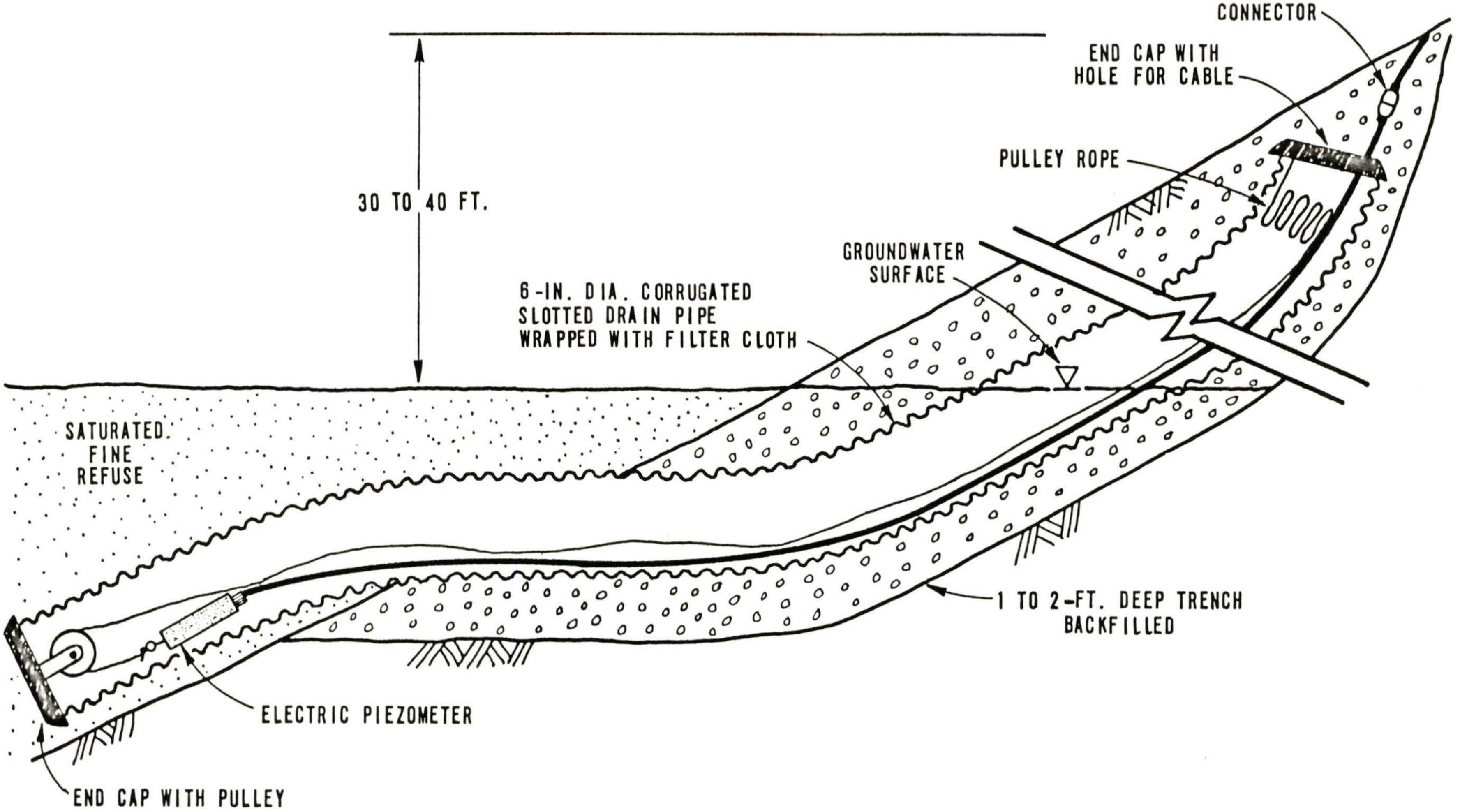


FIG. 4.9 Pond Level Monitoring Device

perforated plastic drainage pipe was covered with filter fabric and buried in the fine refuse. A resistance piezometer, as described earlier, was then pulled inside the pipe to measure the pressure of the overlying water. An electrical cable connects the piezometer to the instrument trailer. It was intended that the piezometer be retrievable to permit recalibration or replacement; in reality, this was not successful.

The seepage volume measuring device consists of: 1) a small bulkhead structure constructed across an established seepage channel below the impoundment structure, 2) a "v"-notch plastic plate built into the bulkhead structure, and 3) a sensitive water level monitoring instrument. Flow volumes are then calculated from the height of the water flowing over the notch. A Leupold & Stevens Model 71 mechanical water level indicator was used, but was modified by adding a rotary potentiometer and electrical cable. The rotary potentiometer allows the water level indicator to be remotely monitored, as well as with the mechanical strip chart recorder. The mechanical recorder contains enough paper for one year and is driven by a six-month spring.

The meteorological parameters measured at this site include temperature, precipitation and barometric pressure. Temperature was measured using two type "T" thermocouples, one inside the instrument trailer and one outside the trailer. Precipitation was measured with a Leupold & Stevens water level indicator and rain collecting system located within the instrument trailer. Precipitation is collected by an 8-inch diameter funnel located on the trailer roof and carried by plastic tubing to an 8-inch diameter, 36-inch high precipitation bucket located inside the trailer. The float of the mechanical water level recorder is suspended inside the bucket, registering rainfall.

Barometric pressure was measured using a Setra Model 260 barometer. The barometer measures changes in barometric pressure by measuring the change in capacitance between two quartz plates. The capacitance varies due to changes in the distance between the plates caused by atmospheric pressure changes.

4.2.2.2 Data Acquisition System

All sensors were designed to facilitate manual reading at or near the top of the borehole in which the instrument was placed. For most sensors the electrical cable running out of the borehole was connected into a junction box near the borehole. Two junction boxes (CJS-1 and CJS-2) were used on the 1120-foot bench to provide nearby lightning projection and to consolidate the number of cables leaving the bench into two heavy 56-conductor cables and 5 vibrating wire piezometer cables. The cable junction boxes were designed and built by Slope Indicator Co. for this project. Those sensors not connected directly to a junction box had a pair of connectors at the top of the borehole.

All cables which ran to the site trailer were terminated in a large junction box mounted inside the trailer which provided lightning protection as well as functioning as a patch panel.

The overall block diagram of the data collection system is shown in Figure 4.10. The sensors were, of course, located in or on the embankment. The electronic monitoring equipment was housed at one end of a 28-foot long by 8-foot wide by 8-foot high trailer. The signal conditioning equipment for this system consisted of three individual units: A Slope Indicator Model 56434 signal conditioning unit; an Irad Model MB-6-7 portable vibrating wire readout, and an Irad

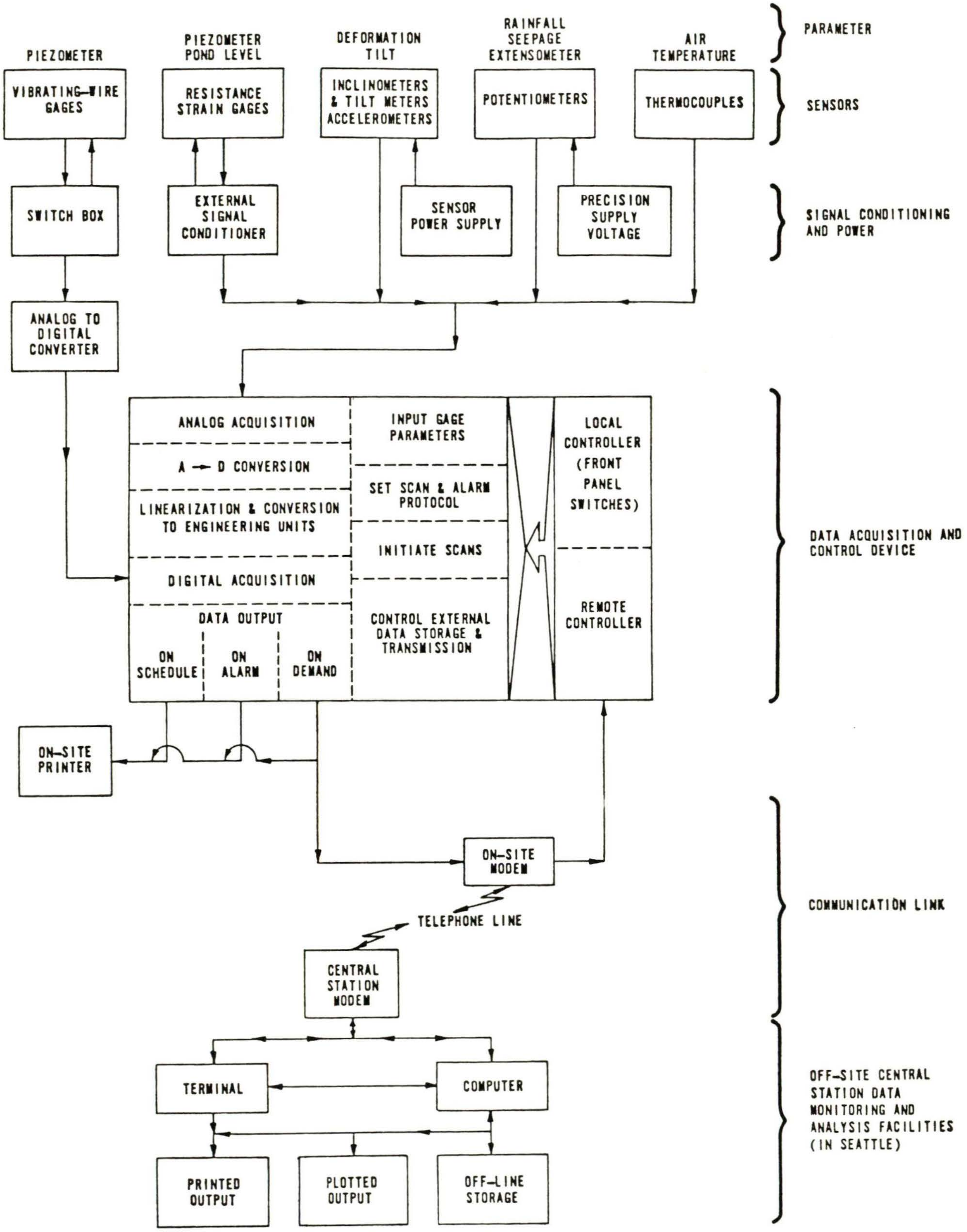


FIG. 4.10 Block Diagram of Remote Instrumentation System

Model MA-5-SM switchbox. The two Irad units work in conjunction to read the vibrating wire piezometers and provide a digital output from the piezometers to the data logger. The Slope Indicator Co. unit provides electrical power, DC voltage, to the remaining sensors when required. In addition, the unit provides signal conditioning for the resistance piezometers as well as remotely controlled, adjustable voltage for the linear and rotary potentiometers.

The heart of the data acquisition system is an Acurex Autodata 9 data logger. This data logger controls the time at which readings are taken, converts the analog voltage readings to digital data, responds to external commands, linearizes data, adds engineering units, and scans data for alarm conditions. These functions are outlined on Figure 4.10. Transmission of data to off-site facilities was through commercial dial-up telephone lines using low speed modems at each end. The trailer (Figures 4.11 and 4.12), including lights, heating and air conditioning, and electronic equipment, was designed to be powered by 120 VAC 60 Hz mains power. Electrical power to the instruments was conditioned by two units, a special Slope Indicator Co. supplied voltage regulator with lightning protection and an off-the-shelf Sola power conditioner.

The off-site central data station for this project was located at Shannon & Wilson's Seattle office. Both simple typewriter and computer terminals were used on this project. The computer, a PDP 11/34 with disc data storage, has a time sharing operating system. In the original design, the transfer of data from the data logger to the computer was initiated through an autodialer with optional interrogation mode. Later modification to the system eliminated the auto-initiate mode due to limitations within the Acurex Autodata 9.

4.2.3 Field Installation Procedures

4.2.3.1 General

All borings were completed with a CMI Model 55 drill using a 6½-inch O.D. hollow-stem auger. Borings were drilled either to bedrock or to a predetermined depth into the fine coal refuse. An NX diamond core barrel was used to drill into bedrock. A log of each borehole is presented in Appendix C. At least one Standard Penetration Test (SPT) was taken at each borehole, but only a few samples were taken since the subsurface conditions had been explored earlier by D'Appolonia Drilling, Inc. The borings and samples confirmed our expectations, except that the depth to bedrock was deeper in the center of the old valley than anticipated. The cross sections in Figures 4.3 and 4.5 show the subsurface profiles as determined by our drilling. No tests were performed on either SPT samples or bedrock core, although the samples were stored in the trailer for possible future use.

4.2.3.2 Piezometers

A standard split-spoon sample was taken at the bottom of the hole before placing the piezometer tubing. Two-inch diameter schedule 40 PVC pipe was used in all piezometer installations. Pipe was supplied by Hydrophilic, Inc., and had machined ends for flush coupling. The bottom section of pipe was sealed at the tip and slotted over the lowermost three feet. The slotted portion was wrapped with filter fabric to prevent clogging of the 0.01 inch wide slots. Individual sections were cemented together with PVC solvent cement and placed through the center of the auger string as shown in Figure 4.13. After placing the pipe, the auger was removed and sand placed around the tip for a depth of about ten feet. A seal of

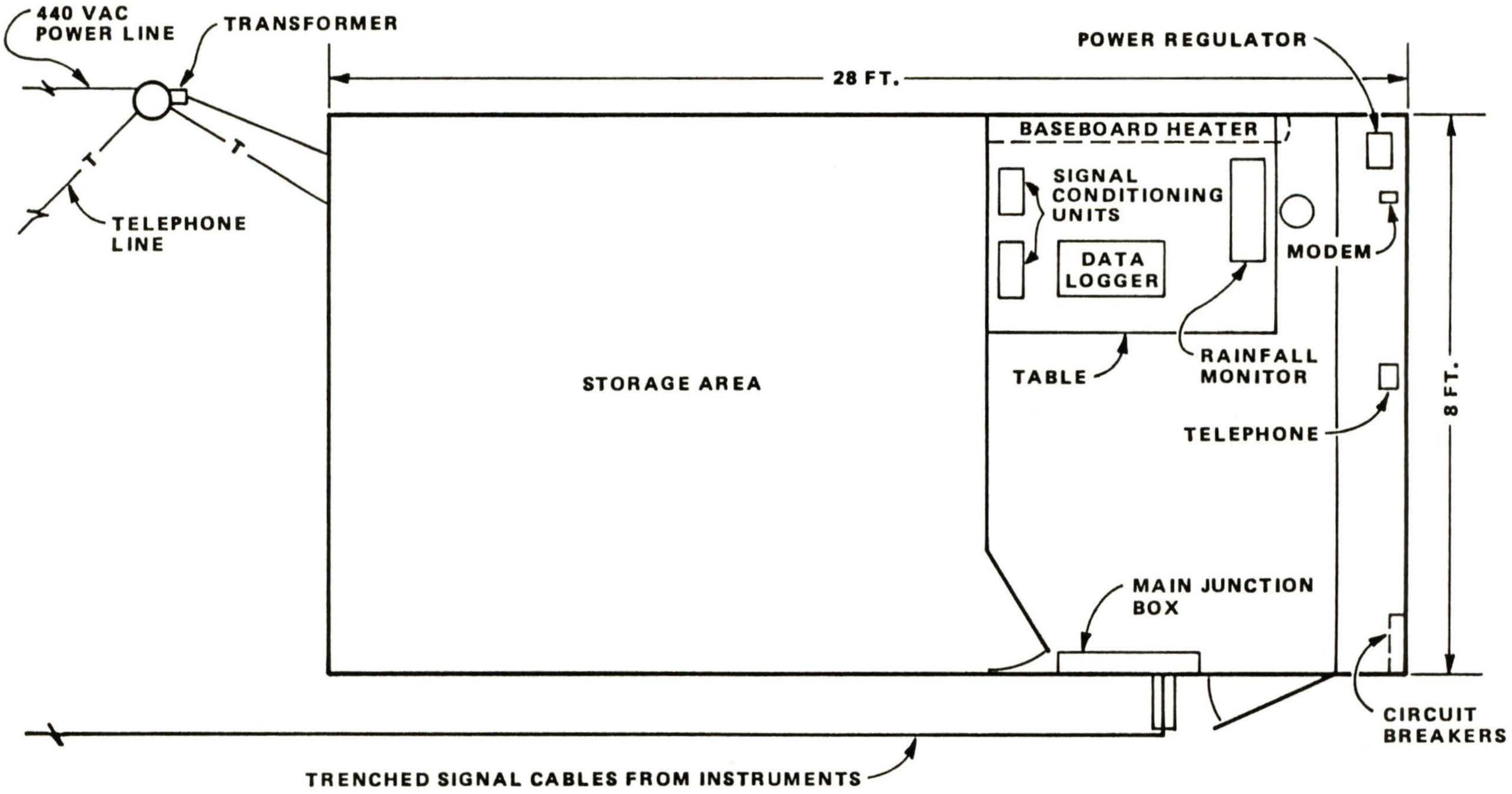


FIG. 4.11 Plan View of On-Site Trailer

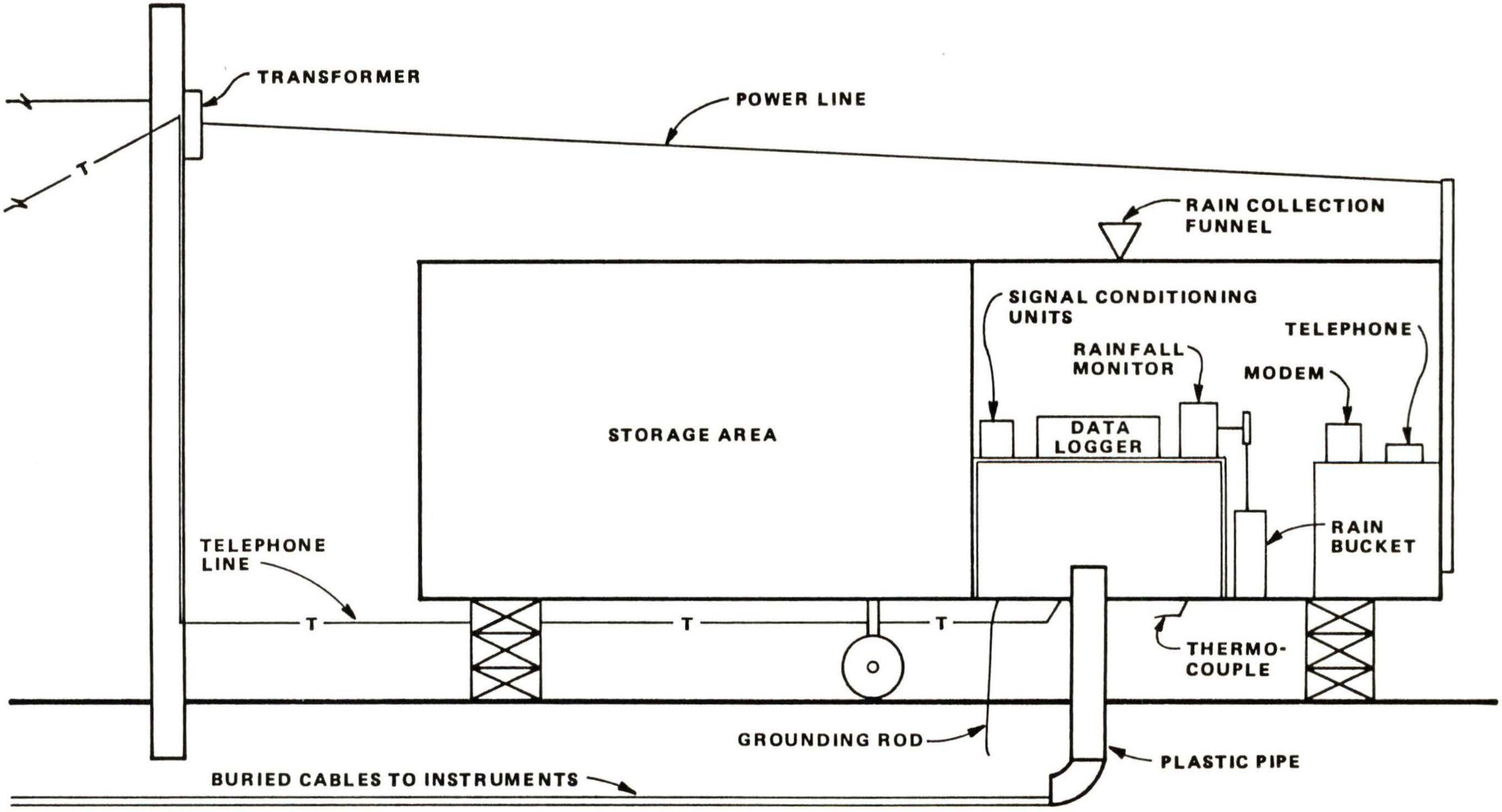


FIG. 4.12 Vertical Cross-Section of On-Site Trailer

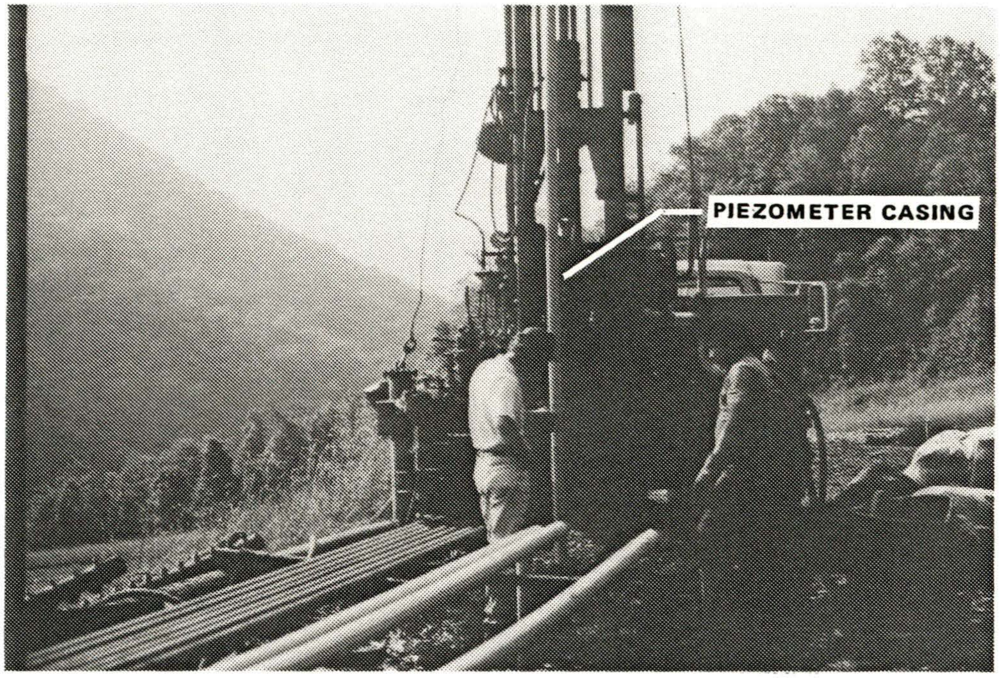


FIG. 4.13 Piezometer Casing Installation

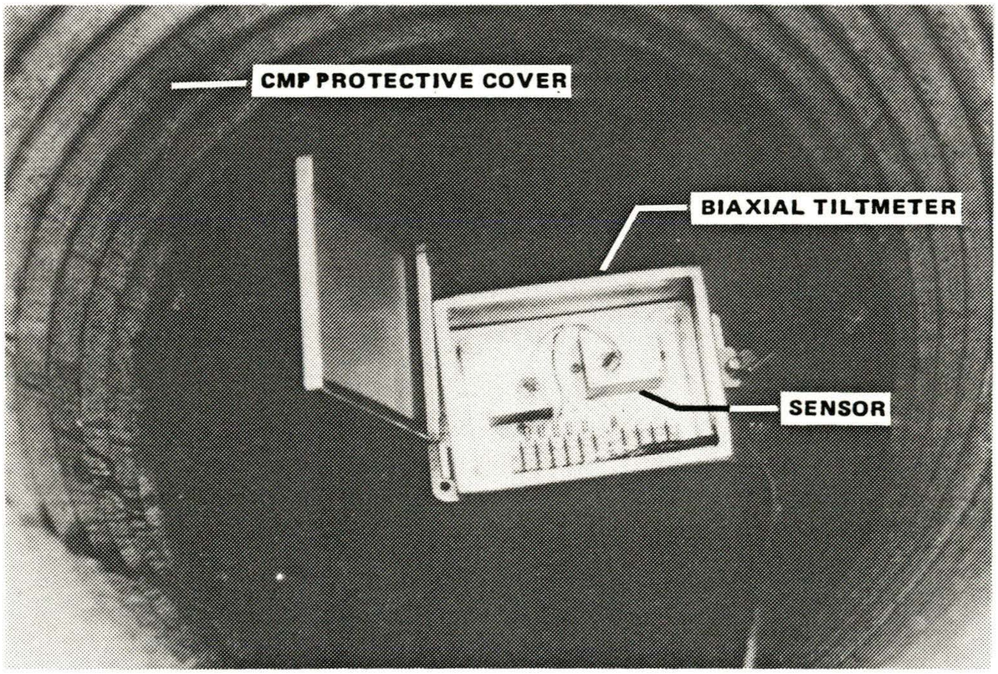


FIG. 4.14 Tiltmeter Installation

either bentonite pellets or lime-cement grout, or both, was then placed above the sand. The remainder of the hole was then backfilled with drill cuttings. After installation, the standpipe was filled with water and the level monitored for several days. The final water level was then compared to water levels observed during drilling to determine if the well was performing satisfactorily. Later, a 12-inch diameter corrugated metal pipe cover was installed over the piezometer. All seven standpipe piezometers performed satisfactorily at the time of installation. Water levels in the piezometers were measured manually at the time of installation and on subsequent field trips with a water level indicator manufactured by Slope Indicator Co. This dipmeter uses two wires within a cable marked at 5-foot intervals to indicate the water level.

Electrical piezometers were suspended in the standpipes by first measuring the depth of the standpipe with a tape and weight and then lowering the sensor to the bottom of the hole. The electrical leads were connected directly to a junction box or to a buried cable leading to the junction box.

Two types of piezometers were installed at this site utilizing two methods of measuring the water pressure in the open standpipe. Seven of the nine piezometers were vibrating wire gages described in earlier sections, manufactured by Irad Gage Co., while the other two resistance piezometers were supplied by the Slope Indicator Co. These two piezometers were installed in different standpipes, but each of the standpipes had a vibrating wire piezometer installed as a check.

4.2.3.3 Tiltmeters

The three biaxial tiltmeters were mounted on top of 2-inch diameter, six-foot long galvanized steel pipe concreted into a 7 to 9-foot deep auger hole. The pipe was centered, leveled, and the threaded end taped to keep the threads clean. After the concrete had set the tiltmeter was attached to the threaded end of the pipe and the sensors oriented in the desired directions. A protective cover, either 12-inch or 24-inch diameter, depending on the tiltmeter model, was placed over the installation (Figure 4.14).

4.2.3.4 Inclinometers

A single in-place inclinometer was installed on the site and was located on the north side of the valley (see Figure 4.5). A boring was augered down to bedrock and then seven feet of rock was cored. The 2.75-inch O.D. inclinometer casing was assembled in twenty-foot sections with couplings attached by aluminum rivets and solvent cement. The casing was then assembled section by section while being lowered inside the auger. The casing sections have four longitudinal grooves spaced equidistant around the inside of the casing. The grooves guide sets of spring-loaded wheels attached to the sensors and, thereby, orient and center the sensors within the casing. An alignment tool was used to keep the grooves between adjacent sections of casing aligned during coupling. The bottom of the first section of casing was capped with a grout valve (Figure 4.6). Once the casing was installed to the bottom of the hole and at least four feet into rock, drill rod inside the casing was used to pump grout around the casing. Drill rod was lowered inside the casing until it fitted over the grout valve stem and sealed on the rubber gasket. The lime-cement grout, the same mix as used with the rod extensometers, was then pumped down the rod until the entire inclinometer casing was surrounded with grout. The auger was then removed from the hole and grouting completed. Finally, the drill rod was lifted off the grout valve stem and flushed thoroughly with clean water before extracting it from the casing. The grout was allowed to set for several days, after which the casing was surveyed twice with a portable inclinometer. The major groove axis of the casing has a magnetic azimuth of 50 degrees.

The in-place inclinometer sensors were installed several weeks after the casing with the help of a technician from Slope Indicator Company. The uniaxial servo-accelerometer sensors were installed along the major axis of the casing with the "A-" side downstream. The eight sensors each have a gage length of 8 feet and with the lowest sensor at the bottom of the casing, for a total length of 64 feet. This depth increment covers the approximate thickness of fine coal refuse. Sensors were attached one on top of each other while being lowered down the casing on a winch (see Figures 4.6 and 4.15). Once all of the sensors were linked together, enough sections of stainless steel rod were connected to lower the sensors to the bottom of the casing. When assembled, the entire sensor string is suspended from the top of casing. Immediately prior to installation, each sensor was checked for continuity, electrical "noise" and polarity.

4.2.3.5 Borehole Extensometers

Boreholes for the extensometers were drilled with the same drill rig as for the piezometers. The holes were augered through the refuse until auger refusal. Then the drill rig was switched to rotary operation and the rock was cored for four feet.

While drilling was being accomplished, the extensometer was assembled. The hydraulic anchors were first laid out on the ground and hydraulic tubes unwound to their full length. Stainless steel rods and protective plastic pipe were connected together starting at the bottom and continued until the designed length was reached. The plastic grout tube was connected to the deepest anchor and laid out alongside the hydraulic tubes. Shallower anchors were laid alongside the hydraulic tubing at the design spacing. Once all of the tubing and pipe were laid out, duct tape was used to bundle the tubes and pipes together at 10-foot intervals. The upper ends of the PVC tubing and hydraulic tubing were then marked with the anchor depth and number. After completing assembly, the entire unit was carefully lowered through the hollow-stem auger flights until the lowermost anchor was at the bottom of the borehole (see Figure 4.16). A weak lime-cement grout mix consisting of 150 lbs of hydrated lime, 94 lbs Portland cement, and enough water to make 50 gallons of grout was pumped down the grout tube. After several barrels were pumped, the auger was withdrawn 20 feet and the bottom anchor was expanded using a hydraulic pump. Grout pumping and auger flight section removal alternated until the hole was filled with grout and all auger sections were removed. The remaining hydraulic anchors were expanded and the top of the hole filled with sand after the grout settled. A reference head (see Figure 3.1) was installed over the rods by first threading and sliding two spacer plates along the rods, then sliding the three-inch diameter steel pipe over the spacer places and rods. The steel pipe was grouted into the borehole collar. The rods were then measured and cut to a length such that the linear potentiometer would initially be deflected one inch. Finally, the reference head was mounted on the pipe and the linear potentiometer wires were connected to buried wires which lead to the cable junction box. Protective corrugated metal pipe covers were placed over the reference heads to protect them.

An error in a cross section of the valley beneath the embankment as shown in D'Appolonia, Inc.'s report required shifting all the borings

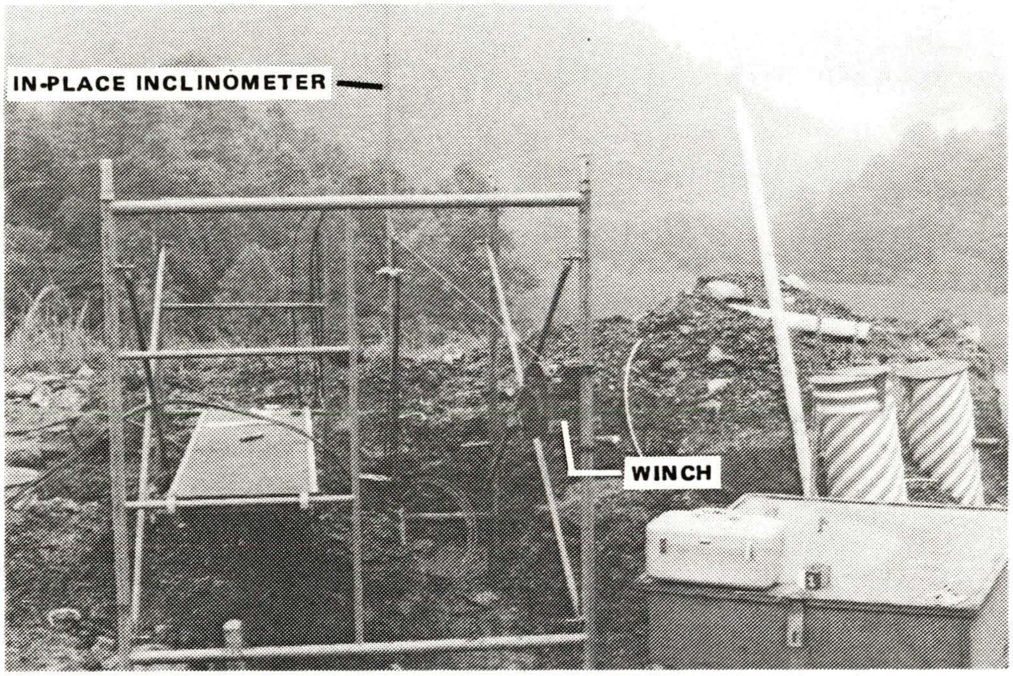


FIG. 4.15 In-Place Inclinometer Installation

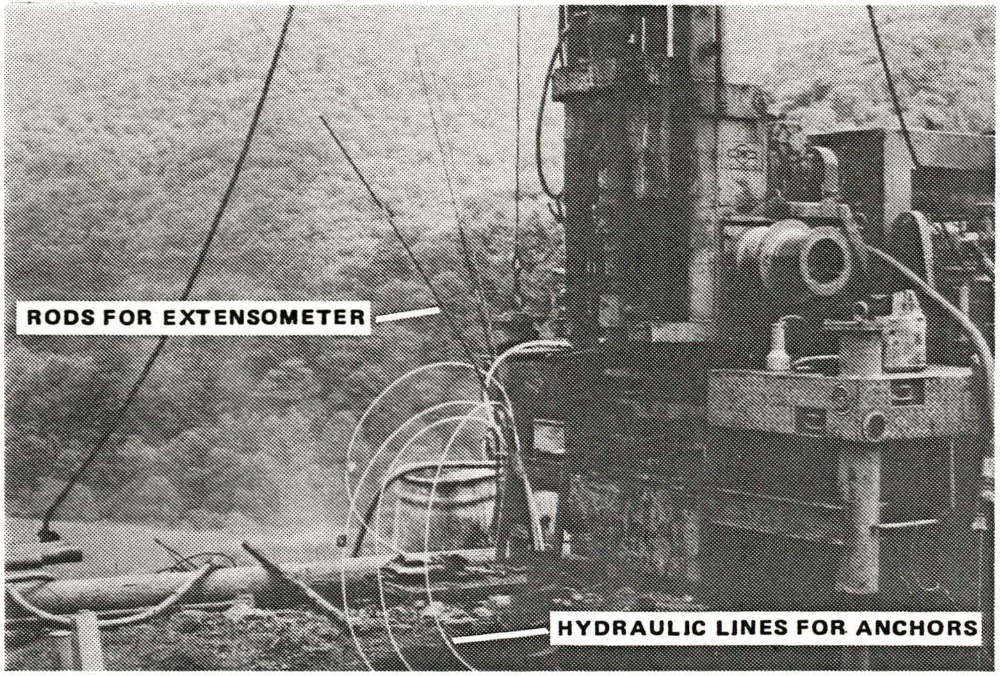


FIG. 4.16 Multiple-Position Borehole Extensometer Installation

approximately 65 feet north of the anticipated positions. The actual positions of the borings are as shown in Figure 4.4. The first multiple-position extensometer, MPBX-1, was drilled near the in-place inclinometer, and VWP-1 on the north side of the valley. This extensometer had four rods with anchors at depths of 140.7 feet, 109.0 feet, 74.6 feet, and 21.0 feet. MPBX-2 was drilled near the center of the valley and had two rods with anchors at 176.3 feet depth and 76.6 feet depth. MPBX-3 was drilled on the south side of the valley near a shallow piezometer, VWP-4, and a tiltmeter, TM-3. This extensometer had the anchors at 171.5 feet depth and 74.5 feet depth. The linear potentiometers used with all the extensometers had an electrical resistance of 10 kilohms and a four-inch stroke. The potentiometer shaft was kept in contact with the extensometer rod by a spring.

4.2.3.6 Electrical Cable and Junction Box Installation

All electrical cable used in this project was rubber or polyethylene sheathed. The rubber-sheathed cable was used only on the downhole connection to the vibrating wire piezometers; all other was polyethelene sheathed direct burial cable. Two cable junction boxes were installed along the 1120-foot bench. Junction boxes were located near clusters of boreholes to reduce the amount of cable necessary to connect the sensors together and eliminate the need for an electrical connector at the top of the borehole (see Figure 4.17). The purpose of the junction boxes was to provide lightning protection, voltage regulation for certain sensors, and reduce the number of cables leading to the on-site data collection station. Voltage regulation was provided for the tiltmeter and in-place inclinometer sensors as well as lightning protection for each electrical conductor, including cable shields. The large number of wires in the center of the junction box, Figure 4.17, are part of a 56-conductor cable which leads to the on-site data station. All conductors, with the exception of the vibrating wire piezometers which require separate shielding, are included in this single cable. By combining the conductors, cabling costs were reduced by about 60 percent between the junction box and the trailer.

The cable junction boxes were made of fiberglass and had a rubber gasket on the lid and compression seals around each cable. Electrical components were specifically selected for temperature and humidity stability. The junction boxes were protected by a heavy sheet metal box which was buried over the top of the junction boxes. Lightning protection consists of gas ionizing tubes designed to short the conductor to ground when the voltage exceeded 150 volts. Other electronics within the sensors are generally able to protect the sensor when the transient voltage is reduced to 150 volts.

The vibrating wire piezometers require individually shielded cables because of the frequency nature of their signal and are only connected to the junction boxes to obtain lightning protection and to allow access to test the sensor near the top of the borehole. Several sensors located off the 1120-foot bench were not connected via a cable junction box, but were connected directly to the on-site data station. These sensors, VWP-5, VWP-6, VWP-7, PLS, and the weir, did not have lightning protection.

All cable was buried between the sensors and the on-site data collection station at the locations shown in Figures 4.1 and 4.4. Trenches were 18 to 24 inches deep (Figure 4.18), except at roadway crossing where they were deepened 24 to 36 inches. Cables were either encased by plastic pipe or covered with sand where buried beneath the roadways to reduce the possiblity of damaging the cable.

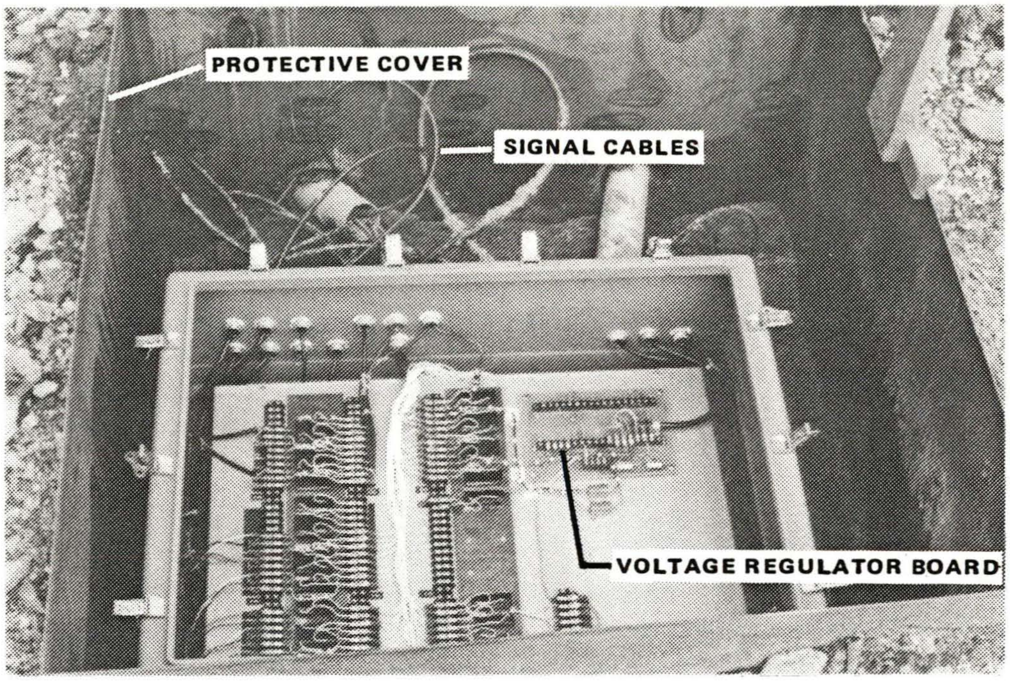


FIG. 4.17 Electrical Cable Junction Box

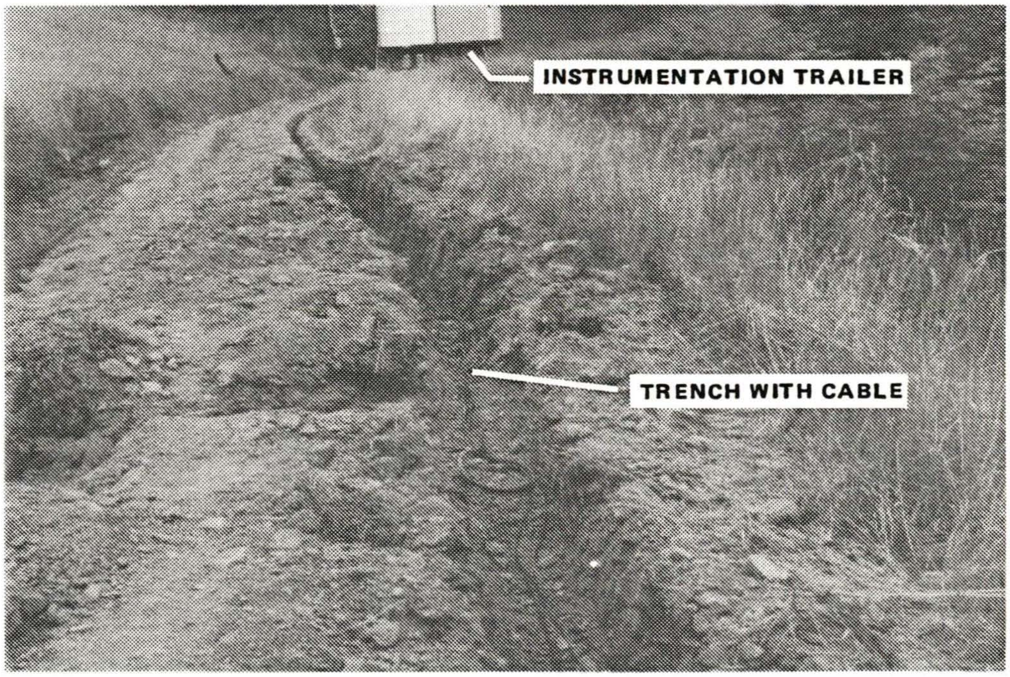


FIG. 4.18 Cable Burial

The cables entered the trailer (on-site data collection station) through a plastic pipe and into the main junction box. This junction box provided both lightning protection for the signal conditioning equipment and a place to manually monitor signals from both sensors and signal conditioning equipment. The lightning protection was similar to that provided adjacent to the sensors.

4.2.3.7 Weir

A small seep located near the haul road was chosen to demonstrate the capabilities of a weir as a seepage flow monitoring device. This small seep was chosen because of its proximity to the other instruments. A backhoe was used to excavate around the seep and a plywood bulkhead installed to impound enough water for the float chamber. The plywood was coated with roofing asphalt to protect it and asphalt mixed with the soil surrounding it to provide a seal. The front of the bulkhead, Figure 4.19, had a 22° plastic-edged "V" notch cut in it to allow the water to flow out. A metal float was positioned in one corner of the bulkhead. A Leupold & Stevens Model 71 recorder was connected to the float and water elevation was recorded both mechanically on a strip chart and electrically with a rotary potentiometer.

4.2.3.8 Pond Level Sensor

The pond level sensor, described earlier and shown in Figure 4.9, was not installed during the summer of 1979. The corrugated plastic tube was mis-shipped and arrived too late at the end of July. Also, more electrical cable than was on-hand was found to be needed to reach the trailer. The cable was extended and the sensor, together with pipe, was installed by hand in January 1980.

4.2.3.9 Meteorological Instruments

The Setra barometer was installed inside the trailer and connected to the ±12 VDC power supply and the data logger. Installation in the trailer provided easy access and a relatively benign environment. One of the two thermocouples was installed in the air space beneath the trailer to measure outside air temperature while the other thermocouple remained in the trailer.

The rainfall collection funnel was mounted on top of the trailer and a plastic tube fed the water into the collecting bucket within the trailer. The recording monitor, pulley, and float was positioned above the collecting bucket and various wiring connections made to the adjacent data logger and power supply.

4.2.3.10 Data Logger, Signal Conditioning and Communication Equipment

Signal conditioning for the extensometers, electrical resistance piezometers, precipitation monitor, and weir monitor, was provided by a Slope Indicator signal conditioning unit. This unit also supplied power for the tiltmeters, in-place inclinometers, barometer and precipitation monitor. Signal conditioning for the vibrating wire piezometers was provided by the Irad MB-6-7 readout. The output of both conditioning units, along with unconditioned sensor output, were connected to the Acurex Autodata 9 data logger. The data logger (Figure 4.20) performed some data reduction and scaling before transmitting the data to the off-site central data station in Seattle. Once every two days data was collected and transmitted by commercial telephone line to Seattle.

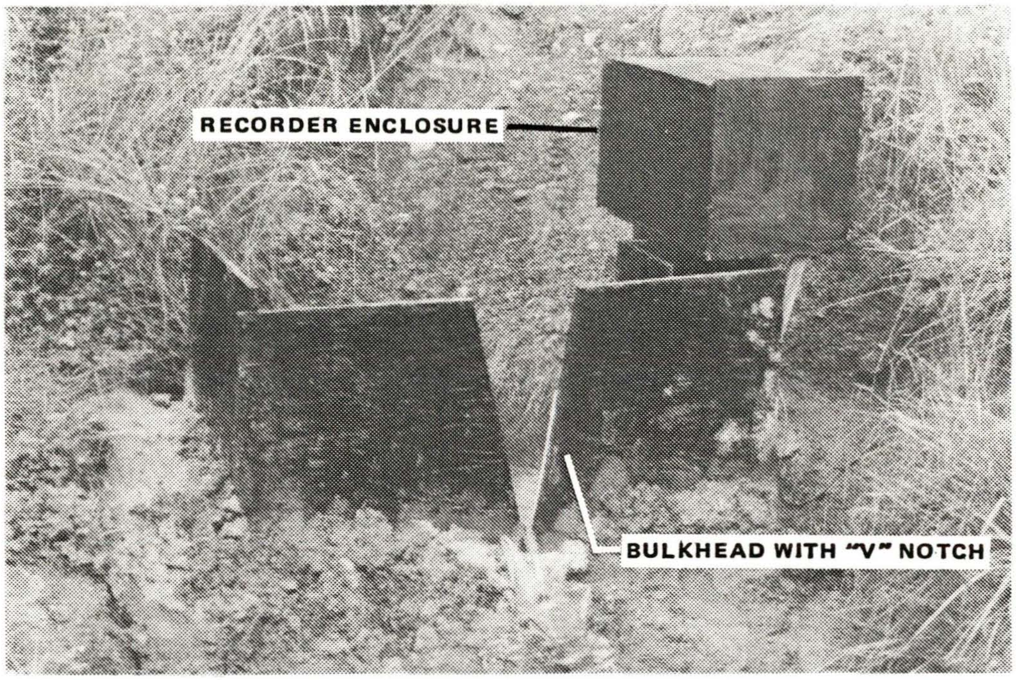


FIG. 4.19 Weir Installation

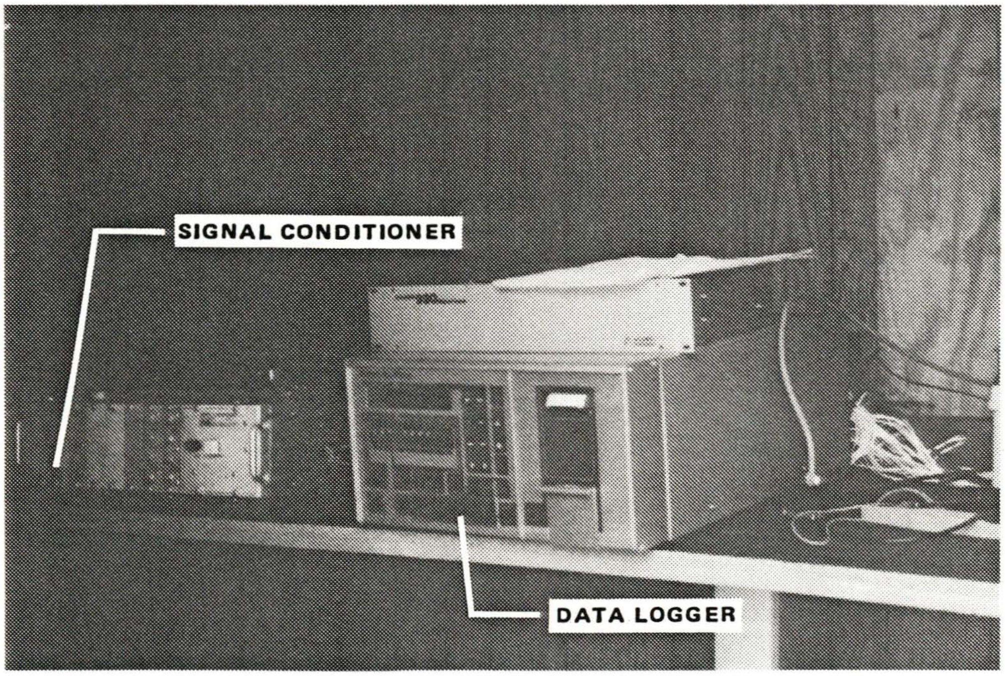


FIG. 4.20 Electronic Equipment within Site Trailer

All electrical connections within the trailer and junction boxes were made with either insulated spade crimp connectors or, when the equipment permitted, the conductors were attached to feed-through terminal blocks. Details of electrical connections for the wiring in the trailer are presented in Appendix D. Relative locations of the various equipment are shown in Figures 4.11 and 4.12.

The electrical power line was installed in July 1979 by the subcontractor. Much of the electronics were installed in July 1979, and left operating at the site until the remaining equipment was installed in January 1980. This delay in equipment installation was caused by the manufacturer's delay in delivering the data logger. Once the data logger was available, it and the remaining equipment, except the modem, were installed during the first field trial trip.

The telephone line and handset were installed in October 1979 after we had left the field site. The modem was not installed and operating until April 1980 due to an electrical failure which required its return to the factory in January.

4.2.4 Field Monitoring Program

The purpose of the field monitoring program was to collect sufficient data to determine the applicability and reliability of the remote monitoring system. Such information would include resolution of sensors, accuracy of the instruments, short and long-term drift and durability in a typical refuse impoundment. In addition to monitoring the performance of the components of the system, this program would provide both typical embankment data and some site-specific data. The third intent was to provide precursory data in the unlikely occurrence of an instability developing in this impoundment structure.

Following initial evaluation of the site and the relative changes which could be expected, it was decided to collect data from the sensors at a one or two-day interval. This time interval would allow evaluation of daily changes in environment as well as a sufficient number of data points to evaluate electrical drift of the sensors. In addition, the extended monitoring period, caused by equipment malfunction, allowed small movements caused by ongoing construction to be measured.

The initial design intent for data collection was to have data transmission initiated from the on-site data collection center with control of the transmission by the Acurex Autodata 9 data logger. Due to problems with the data logger, the site was called manually to collect data.

During installation in January 1980, the modem failed and no telephone link was established. Following this failure, data were collected automatically on-site by programming the data logger to record the data every two days on paper tape. Later, in April 1980, the repaired modem was placed in service and data were collected by calling the site from Seattle and requesting a data scan (auto-consult mode). The site was called manually, but the data were automatically transferred from the data logger to the computer in Seattle. In addition, the data logger was programmed to automatically record data every two days in case there was another failure of the telephone link.

Once data had been entered into the computer, more detailed analysis could be performed and the data more easily stored. Programs were designed for this particular site to linearize and add engineering units to the data.

Originally, the field site was to have been visited once a month for assessment of the system and repair purposes. However, equipment breakdown and repair necessitated a more erratic visit schedule. Actual field trips took place in January 1980, April 1980, May 1980, and April 1981. A field monitoring trip diary is provided in Table 4.2.

4.2.5 System Maintenance

To determine the operating costs of the instrumentation system, careful records of all maintenance were kept. Whenever practical, individual repair records for each equipment malfunction were kept. Actual costs for each failure are difficult to accurately assess because equipment manufacturers repair costs and replacement part costs are usually only a small fraction of the actual costs associated with the failure. This is particularly true if an important component fails and a special trip to the site from Seattle was required to replace it. Actual field time required to remove or replace a component during a regular site visit have not been included in the cost estimate of the repair, even though several site visits were extended to allow for on-site repair or removal of faulty equipment.

Besides the repairs performed on the system, the field trips also provided the opportunity to perform regular maintenance, such as cleaning out the weir, changing paper tape and batteries on the data logger, winding the spring clock on the mechanical recorders, changing paper on the mechanical recorders, draining the rainwater collection tank, and clearing soil from around the protective CMP covers. Assuming good conditions and no equipment failures, these general maintenance procedures could be accomplished at 6-month intervals.

4.3 System Disposition after Field Testing

On May 7, 1981, the site was shut down and the telephone disconnected. Functioning equipment was left on-site since it was planned to extend the system under a future separate contract to solar power and satellite transmission. Based on our experience at this site, we do not anticipate major vandalism problems or instrument failure. Some equipment, especially in the trailer, may fail due to high temperature and humidity. Those instruments which were malfunctioning were removed from the site whenever possible and returned to Seattle for examination and storage prior to final disposition at the end of this contract.

TABLE 4.2

Field Monitoring Diary

June 4 to July 13, 1979: The fifteen instrumentation boreholes were drilled and sampled. Casing and other instrumentation hardware were installed.

July 1979: The majority of the sensors and some of the data acquisition equipment arrived from manufacturers and was installed on-site. Equipment still not supplied by manufacturers included: conduit for MPBX installations, data logger, 1 vibrating wire piezometer, readout and switching boxes for vibrating wire piezometers, modem, and autodialer for telephone interface. The signal conditioning and power conditioning equipment which was installed on site was turned on and left running when the site was left. It was anticipated that the remaining equipment would be delivered by the manufacturers within two weeks.

October 1979: Telephone line installed to trailer by telephone company.

November 1979: The data logger was finally completed by Acurex and the equipment shipped to Seattle. Modem was mis-shipped and was not located until mid-December. It was discovered that due to change in FCC telephone tariffs an isolation coupler must be installed before the autodialer can be attached and that the telephone connection was not checked out while at factory. A suitable coupler was purchased in Seattle.

December 1979: All remaining equipment arrived and check-out of the equipment in Seattle and interfacing of data logger to Shannon & Wilson's computer was started. Site had not been visited since July and the site visit was put off until mid-January to allow more interfacing time, avoid holidays and allow the Technical Project Officer to visit site with us. Conversations with mine personnel indicated that the power line had been broken in the fall and arrangements were made with an electrical subcontractor to repair the line before the next trip.

January 1980: Upon arriving at site, the -18V DC power supply for the Slope Indicator Co. signal conditioning unit was found to be damaged along with signal conditioning cards. Evidently capacitors and integrated circuits on printed circuit cards had been damaged by high voltage. With spare parts shipped from Seattle, some of the cards were repaired while two cards (for resistance piezometers) were returned to Seattle for repair. On arrival at the site, the telephone line was down but was repaired three days after the breakdown was reported. The data logger, vibrating wire piezometer, signal conditioning unit and MPBX were installed. The connection of one particular vibrating wire piezometer caused problems with the entire vibrating wire measuring system so it was removed and returned to Irad. The modem was damaged during installation and it too was returned to the manufacturer for repair. The barometer was found to be not functioning correctly and was returned to the manufacturer for repair. Since data could not be transmitted over the phone because of the damaged modem, the datalogger was set to automatically record the sensors every two days. The pond level sensor installation was also completed during this trip but was not operational due to the damaged signal conditioning cards. Locations of instruments were surveyed and plotted at this time.

TABLE 4.2 (cont.)

Field Monitoring Diary

April 1980: Barometer, 1 vibrating wire piezometer, modem, and signal conditioning cards for resistance piezometers were brought back to site for installation. The circuit breaker regulating the power for the electronics had been tripped. The failure occurred on the 38th day of the year (i.e., February 7), according to data logger clock. The electronic equipment was then isolated on its own circuit with a new breaker. However, the vibrating wire readout and switching box and an intergrated circuit appeared to have been damaged by whatever caused the circuit breaker to trip. Discussions with Slope Indicator Co.'s electronics staff suggested that the circuit breaker was being indirectly tripped by high voltage transients along the power line. The transients were activating a lightning protection device which, in turn, caused the circuit breaker to trip.

After replacing repaired resistance piezometer cards, the MPBX cards did not work, so they were returned for repair as were the vibrating wire piezometer readout and switch box. The pond level sensor had been buried by the advancing embankment and either it or the cable was damaged. Due to the depth of burial, the pond level sensor was not recoverable. One resistance piezometer (RP-1) was also not functioning and was returned for repair. Analysis of the repair indicated water leakage around the cable connection.

While at the site, we were informed that the AC mains power would be cut off because the adjacent Bethlehem mine from which the power was derived was being shut down. After talking with Bethlehem personnel, they agreed to leave the line operational until the power at the remaining active portion of the mine could be converted to a different system, a time period of one or two months. Communication with our computer in Seattle was established and off-site data collection started.

May 1980: The repaired vibrating wire piezometer read-out equipment, resistance piezometer and repaired MPBX cards were returned to the site but power was off at the site on arrival. Bethlehem personnel had shut off power the previous Friday. A 1.5 KW electric generator was rented and the system placed back in operation but a tiltmeter and one resistance piezometer card were found not to be functioning. In addition, the vibrating wire readout equipment worked for only one day before malfunctioning. The faulty tiltmeter along with another tiltmeter whose readings were drifting and the vibrating wire piezometer readout equipment were brought back to Seattle for repair. Arrangements were made with on-site Armco personnel to operate the electric generator part-time (3 days/week) to allow some data collection.

June 1980: Following a strike at the mine, data collection over the telephone began three days a week using the portable electric generator. Electronics associated with the signal conditioning deteriorated with the final result the -18 VDC power supply shut off. During the second week in June, Armco's equipment operator who was operating the generator became ill and was hospitalized. Consequently, data collection was temporarily discontinued.

February 1981: An SRC technician removed electronic equipment from site trailer and shipped it back to Seattle for testing and repair.

TABLE 4.2 (cont.)

Field Monitoring Diary

March 1981: Equipment from site was repaired and bench-tested in Seattle for one month. In addition, a new power conditioner was purchased for the site.

April - May 1981: Two tiltmeters, Irad vibrating wire readout equipment, Slope Indicator Co. electro-piezometer signal conditioning equipment, data logger, and modem were returned to the site for a one-month period. Upon arriving at the site, it was found that electrical cable buried beneath a haul road had been exposed and broken by a grader. In addition, the barometer, electrical readout of the weir, tiltmeter (TM-1), resistance piezometer (RP-1), rain gage, and some voltage regulators in the cable junction boxes were damaged. The broken cables were eventually traced with limited resources due to a current mining industry strike, repaired as were other instruments, where possible, and data collected on a daily basis. While at the site VWP-5 and VWP-6 failed, as did the switch box for the vibrating wire piezometers. The new power conditioner was installed and the system powered by a rented electric generator. TI-1 was resurveyed with the portable inclinometer probe. The site was shut down on May 8 and all functioning equipment left in the trailer.

5.0 EVALUATION OF INSTRUMENTATION SYSTEM

5.1 Data Reduction and Presentation of Field Measurements

5.1.1 General

The data collected by the instrumentation system, either automatically or by calling the site, was processed by Shannon & Wilson's Seattle computer. This computer, a DEC PDP 11/34 minicomputer, together with a line printer, modem and plotter was used to linearize the data and conveniently store the data. A FORTRAN program was created to accept the raw data from the data logger, linearize the data, and add engineering units. The program is written for the particular type and configuration of sensors at the Montcoal site and would have to be modified for a different sensor configuration. In addition, there are commands in the program which are related to the PDP 11/34 operating program which would have to be modified for use on a different type of computer.

This computer program accepts the raw data line-by-line, multiplies the data by each instrument's calibration constant, adds appropriate units, and then either stores the linearized data on the computer or produces a hard copy on the line printer. Table 5.1 shows an example of the linearized data output. Vibrating wire and resistance piezometers and pond level sensors are all sealed gages that measure absolute pressure and are corrected for changes in barometric pressure automatically during linearization. The voltages from the in-place inclinometers and tiltmeter are simply multiplied by a constant to obtain the horizontal deflection for a standard 8-foot gage length. The extensometers do not require signal conditioning or linearization because the voltage is directly proportional to displacement, and thus this program simply adds the engineering units and instrument designation. Converting weir water height to seepage flow rate requires the use of a table of conversion factors because the flow rate is a nonlinear function of water heights in a "V" notch weir.

In addition to linearization, the computer program checks for control characters within the data which the data logger includes with the data when alarm limits are exceeded. The operator is notified when alarm limits have been exceeded. Besides the instrument data, three channels of test voltages are transmitted. The computer scans these test voltage values and alerts the operator when the values deviate from acceptable limits.

A second computer program takes the linearized data and updates a second set of files which contain the linearized data stored by sensor number. These second files are more easily used for plotting the data. In addition, computer programs were written to quickly plot the data to evaluate any trends. These programs have not been included in the appendix because they are written for a specific type of plotter and are not applicable to most computers.

All pertinent data have been formally graphed as a function of time and will be discussed in the following paragraphs.

TABLE 5.1

EXAMPLE OF LINEARIZED DATA FROM LOWER BIG BRANCH IMPOUNDMENT

```
DATE IS  150    TIME IS  10: 0
VWP-1                    1540.3  ELEV. MSL       VIBRATING WIRE
VWP-2                    1462.9  ELEV. MSL       PIEZOMETERS:
VWP-3                    1519.6  ELEV. MSL     - ELEVATION OF WATER
VWP-4                    1563.7  ELEV. MSL       REFERENCED TO MEAN
VWP-5                    1460.6  ELEV. MSL       SEA LEVEL
VWP-6                    1348.3  ELEV. MSL
VWP-7                    1395.5  ELEV. MSL
II1-1                   -0.1128 IN. DISPLACED
II1-2                   -0.0208 IN. DISPLACED  -IN-PLACE INCLINOMETER
II1-3                   -0.0032 IN. DISPLACED   SENSORS
II1-4                   -0.0296 IN. DISPLACED
II1-5                    0.0024 IN. DISPLACED
II1-6                   -0.0176 IN. DISPLACED
II1-7                   -0.0016 IN. DISPLACED
II1-8                    0.0032 IN. DISPLACED
TM1-1                    0.0605 IN. DISPLACED
TM1-2                   -0.0682 IN. DISPLACED  -BIAXIAL TILTMETERS ON
TM2-1                 ~~-4.2192~~ IN. DISPLACED   1120-FOOT BENCH
TM2-2                 ~~-2.2176~~ IN. DISPLACED
TM3-1                  ~~4.1184~~ IN. DISPLACED
TM3-2                  ~~1.5248~~ IN. DISPLACED
MPBX1-1                  0.2030 IN. DISPLACED   MULTIPLE - POSITION
MPBX1-2                  0.1050 IN. DISPLACED   EXTENSOMETERS:
MPBX1-3                 -0.0020 IN. DISPLACED  _DISPLACEMENTS ARE
MPBX1-4                 -0.0040 IN. DISPLACED   REFERENCED TO TOP
MPBX2-1                  0.1270 IN. DISPLACED   OF GROUND
MPBX2-2                 -0.0070 IN. DISPLACED
MPBX3-1                  0.0260 IN. DISPLACED
MPBX3-2                 -0.5280 IN. DISPLACED
RP-1                      979.1  ELEV. MSL
RP-2                     1036.2  ELEV. MSL    ——— RESISTANCE PIEZOMETER
PLS                      1015.8  ELEV. MSL
WEIR FLOW RATE              4.8  GALLONS PER MINUTE
TOTAL RAIN MEASURED        9.69   IN.
BAROMETRIC PRESSURE       14.18   PSI
INSIDE TEMPERATURE        88.2   F
OUTSIDE TEMPERATURE       81.8   F
```

NOTE: CROSSED OUT DATA WERE NONFUNCTIONING SENSORS

5.1.2 Piezometers

Figures 5.1 through 5.7 show the water levels in the seven open standpipe piezometers as a function of time. Piezometers B-12, B-13, and B-14 (Figures 5.5, 5.6, 5.7) have shown remarkably stable water levels over the past two years with the water level fluctuating less than 5 feet throughout this time period. Daily fluctuations for these piezometers have been two to three feet, which probably represents the influence of variations of precipitation and fine refuse deposition into the impoundment. The deep piezometer on the 1120-foot bench (B-1) has also shown very little pore-water pressure variation. This piezometer, as well as the others downslope, is drilled to bedrock and the pore-water pressure is probably strongly influenced by local bedrock groundwater rather than impoundment pond water level. The shallow wells on the 1120-foot bench (B-3, B-4 and B-7) have shown a slight reduction in water level of approximately 5 feet over the last two years. In addition, daily fluctuations of 5 feet are not uncommon. These piezometers are just within the fine coal refuse which is totally saturated and are well above the original valley bottom. The pore-water pressure at these locations is much more influenced by the daily pumping of fine refuse, rainfall and the changing size of the impoundment structure.

5.1.3 Tiltmeters

Motion of the base of tiltmeters TM-1 and TM-2 towards upstream is denoted as a position deflection on the graphs. Also, a rotation of the tiltmeter towards the south is denoted as a positive deflection for the second axis. For TM-3 motion of the base towards downstream is denoted as a position deflection on the graph, as is a rotation towards the south on the second axis. Movements on all three tiltmeters are presented as a displacement in inches for an imaginary 8-foot long gage length. This gage length was chosen to correspond to the in-place inclinometer sensor gage length. The movement can be considered as either a horizontal displacement per 8-foot vertical gage length or a vertical rise or fall per 8-foot horizontal gage length (see Figure 5.8).

Data from the three tiltmeters are shown in Figures 5.8, 5.9, and 5.10 as a function of time. Data for the tiltmeters are sketchy because two units were returned to the manufacturer for repair. Analysis of data from early 1980 suggests that the 1120-foot bench was rotating very slightly downstream with respect to bedrock. However, removal of two tiltmeters in May 1980 for repair and the subsequent failure of the remaining tiltmeter precluded continued monitoring of this trend since tiltmeters cannot be removed and then replaced on their bases without rezeroing them. Examination of other instrument information, notably the traversing inclinometer, suggests that this downstream rotation may have been the result of using heavy earth-moving equipment near the tiltmeters. Early in 1980, the 1120-foot bench was regraded with topsoil and planted with grass seed.

5.1.4 Inclinometers

Two inclinometer casings were installed within 6 feet of each other on the 1120-foot bench. The in-place inclinometer assembly was permanently installed in one casing (II-1) and the adjacent casing was periodically monitored with a traversing probe inclinometer to provide a cross-check with the in-place units. Removing the in-place inclinometer string is difficult and it is very hard to replace the string of sensors in their exact previous position. However, a portable probe inclinometer can be readily operated in the second adjacent casing and it is

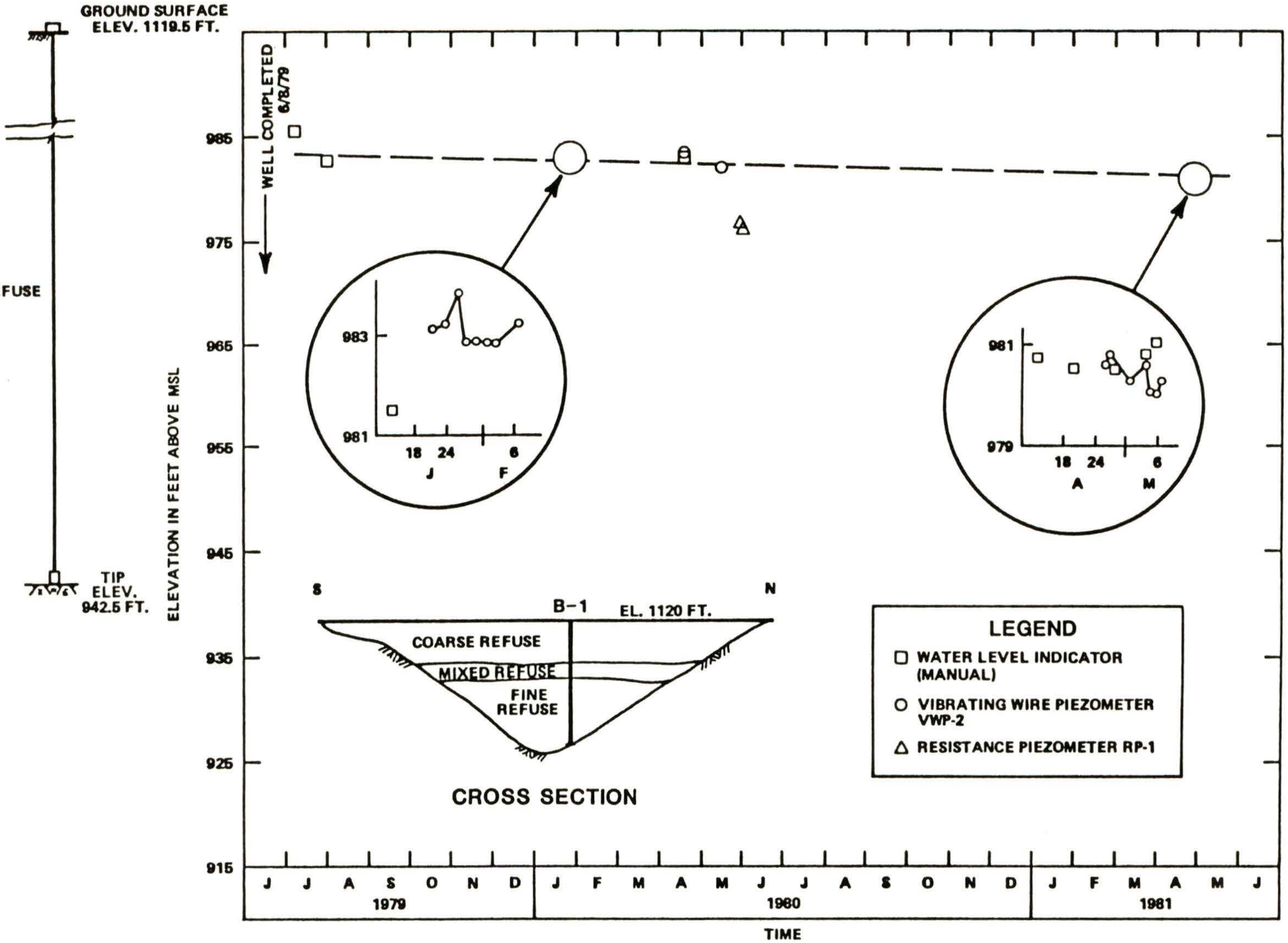


FIG. 5.1 Water Levels for Piezometer B-1

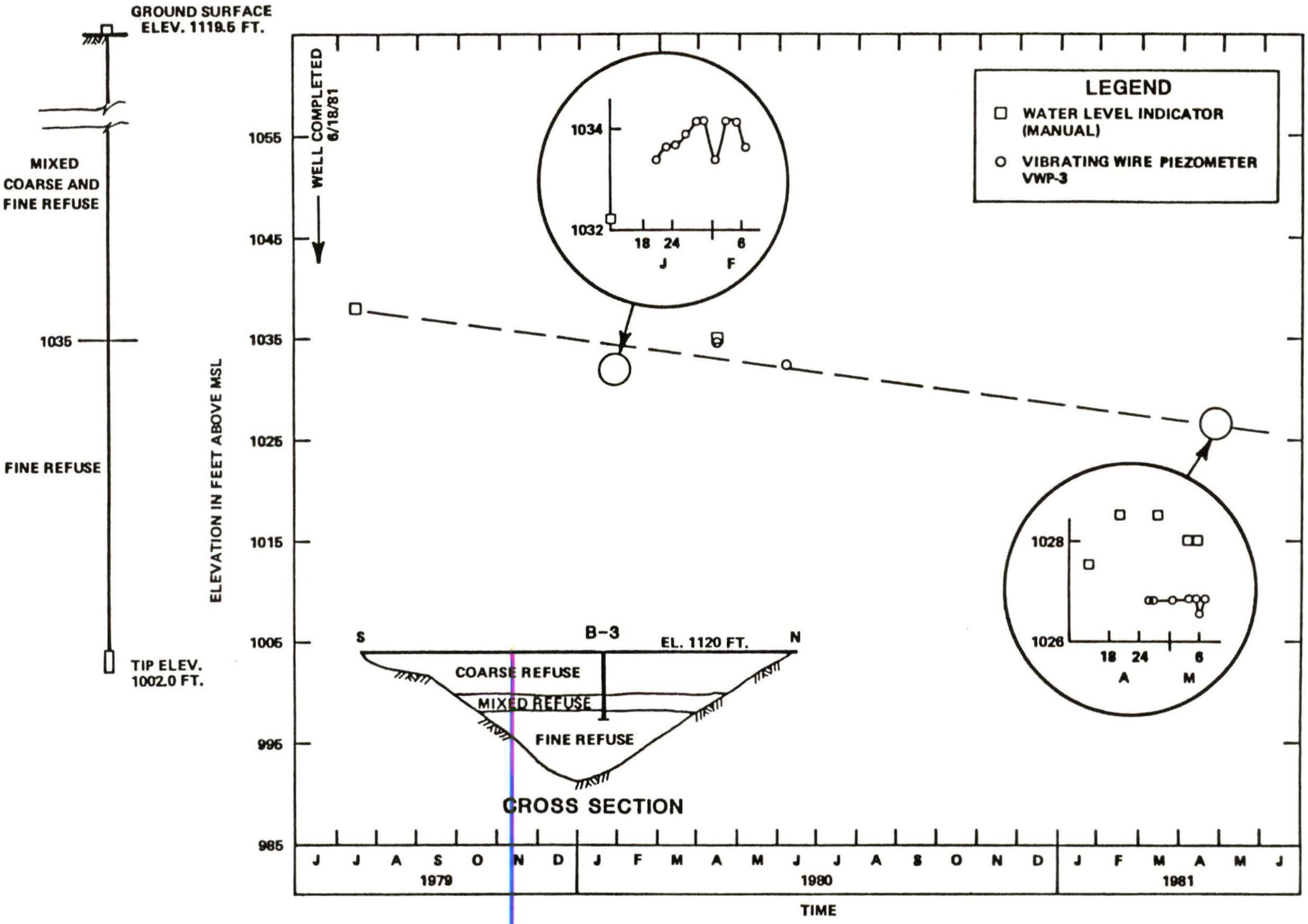


FIG. 5.2 Water Levels for Piezometer B-3

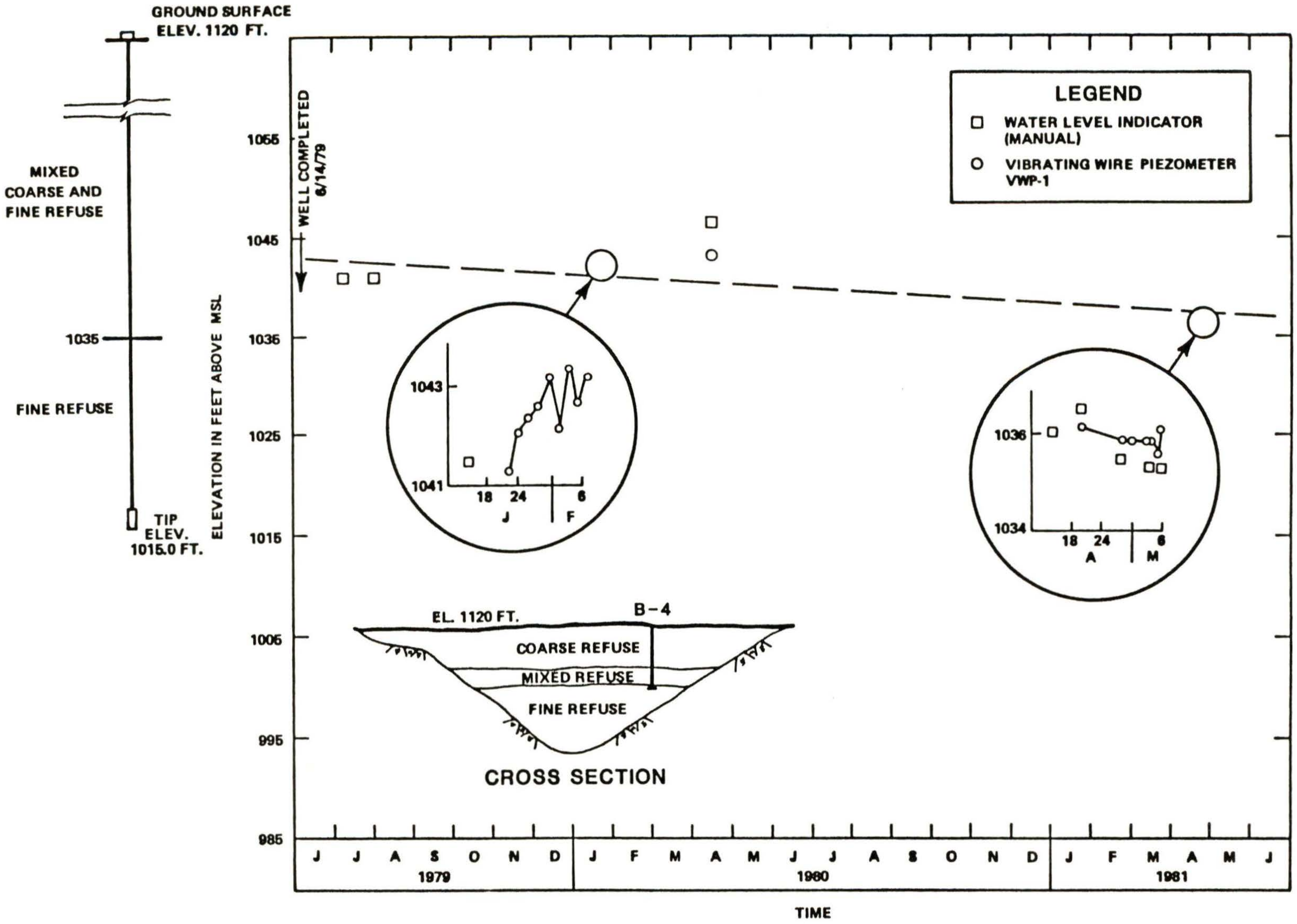


FIG. 5.3 Water Levels for Piezometer B-4

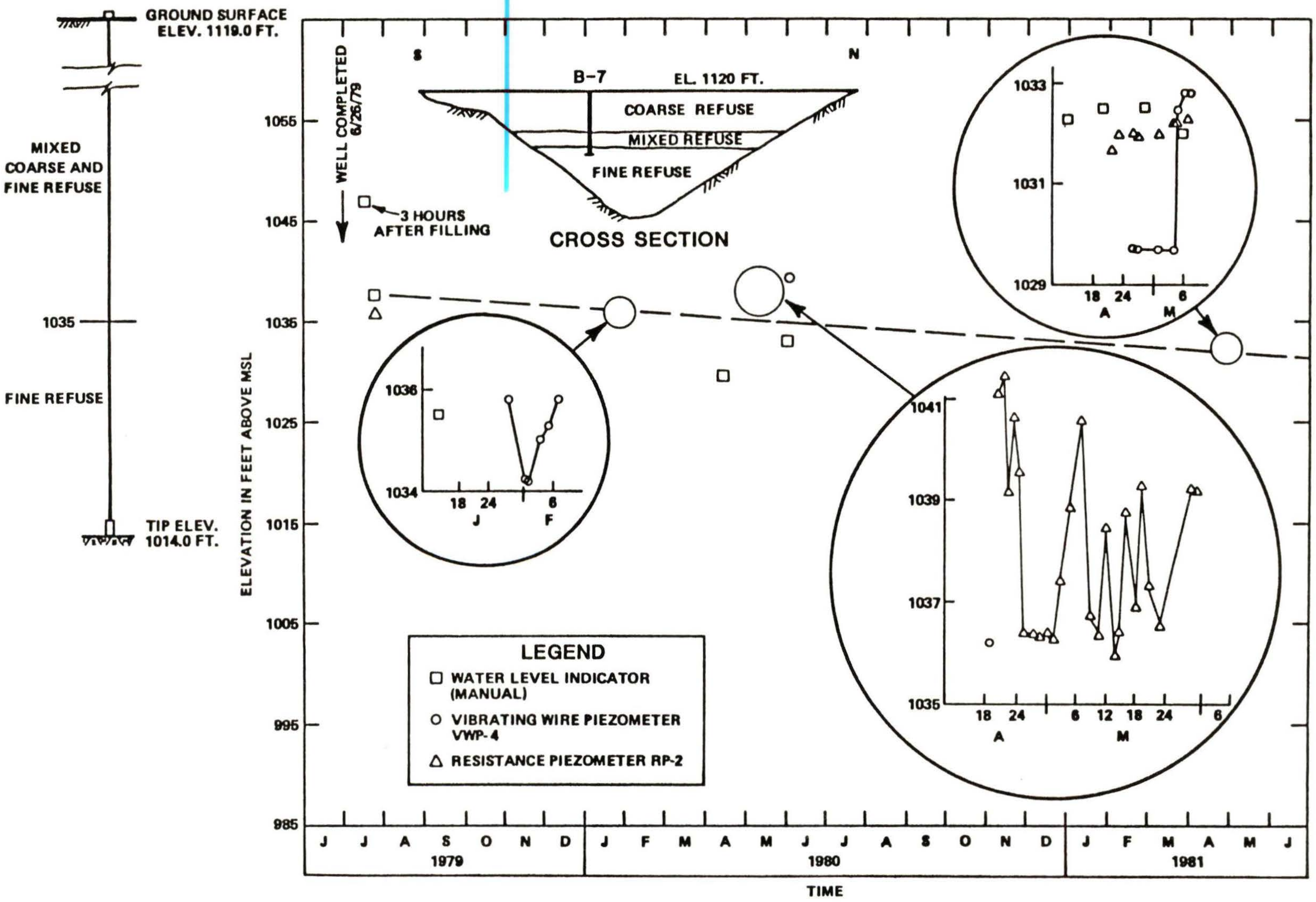


FIG. 5.4 Water Levels for Piezometer B-7

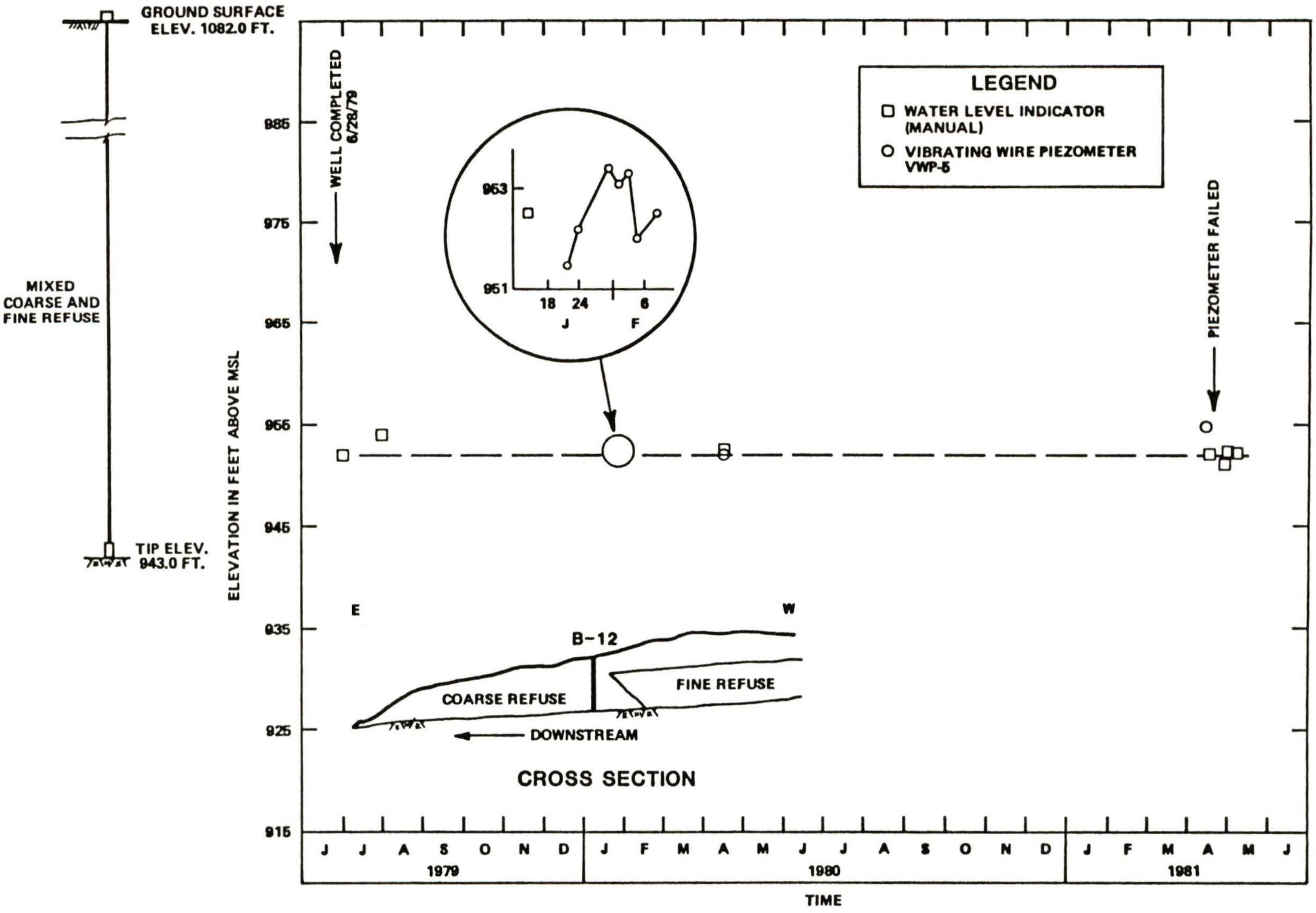


FIG. 5.5 Water Levels for Piezometer B-12

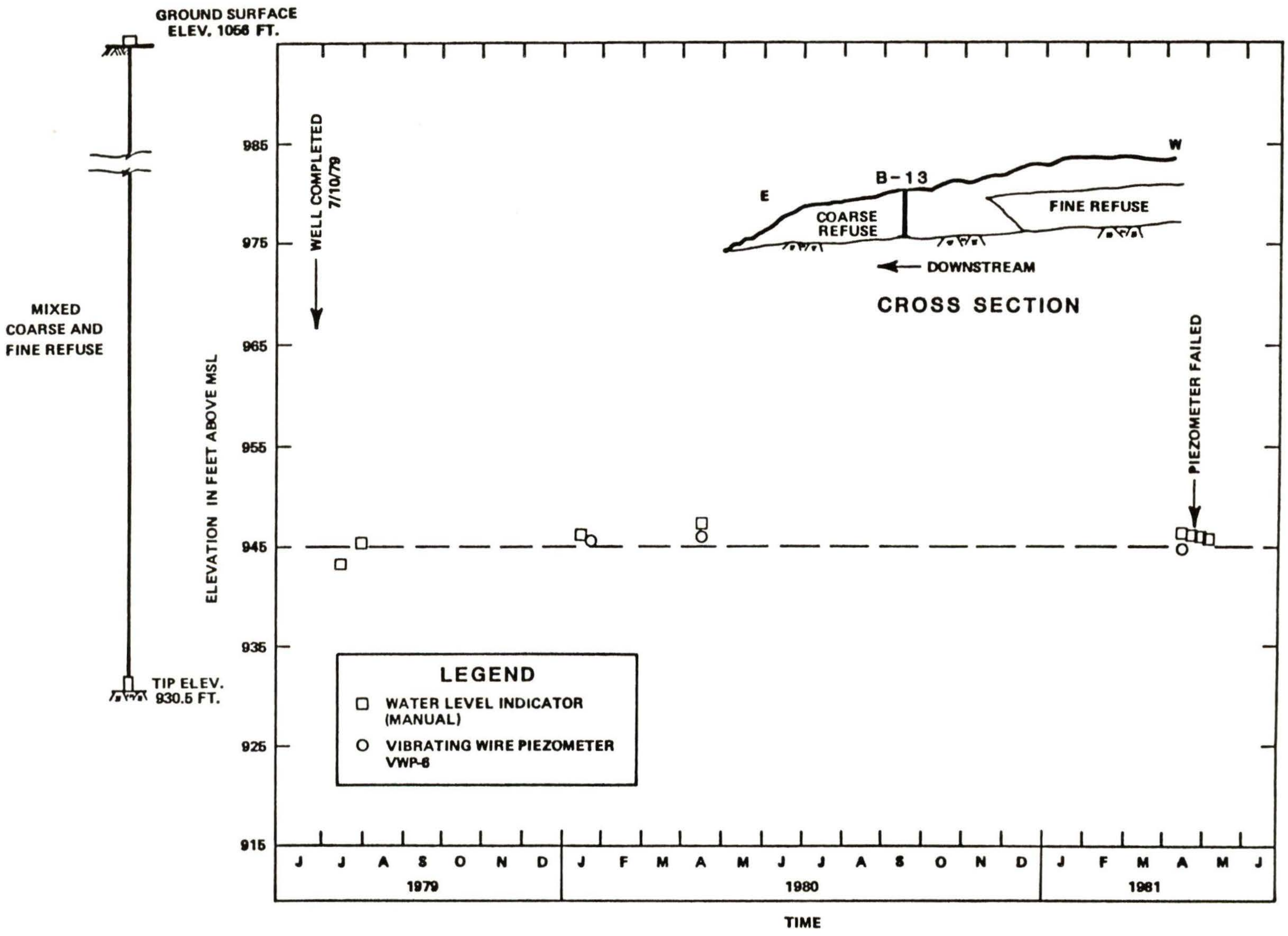


FIG. 5.6 Water Levels for Piezometer B-13

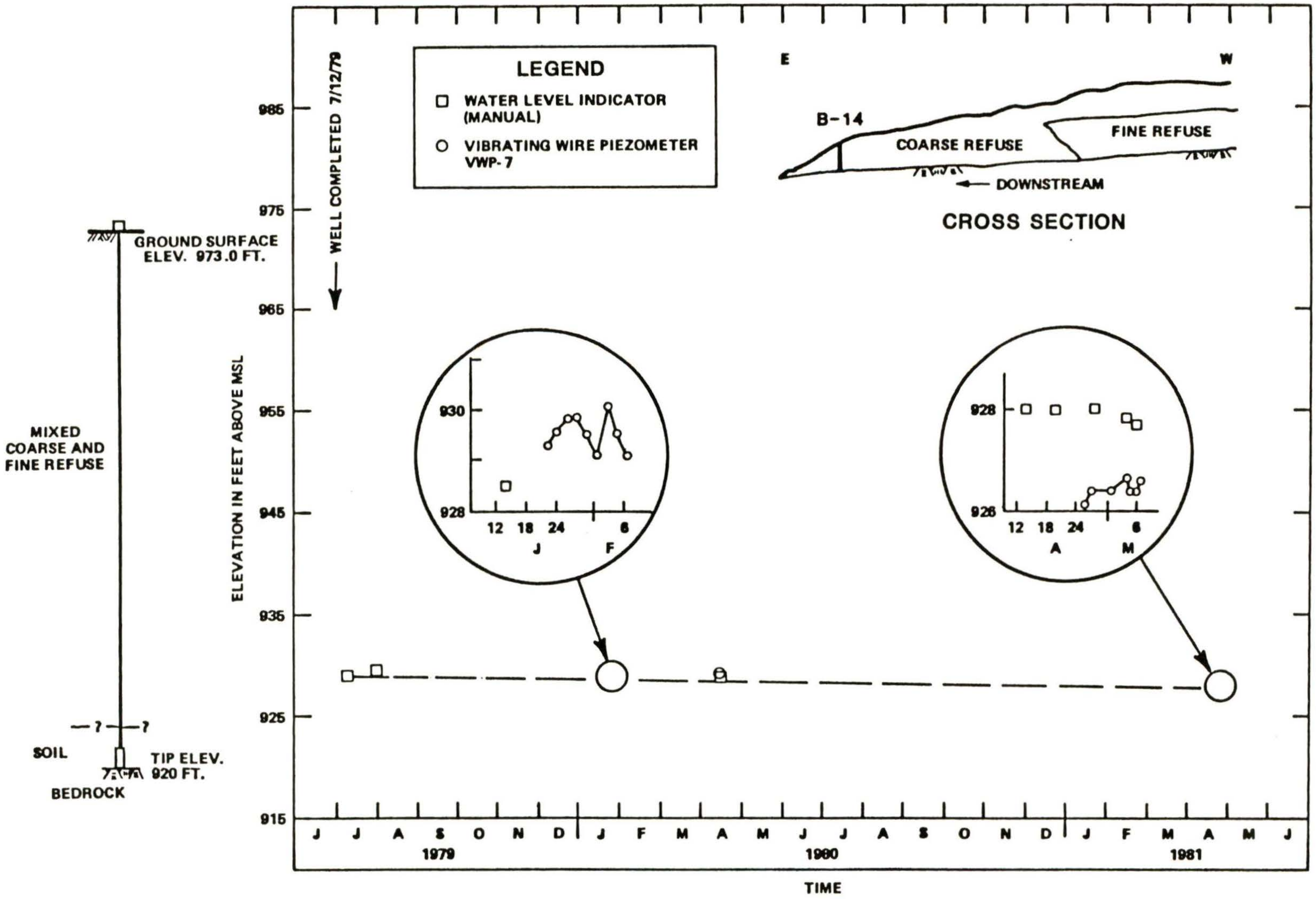
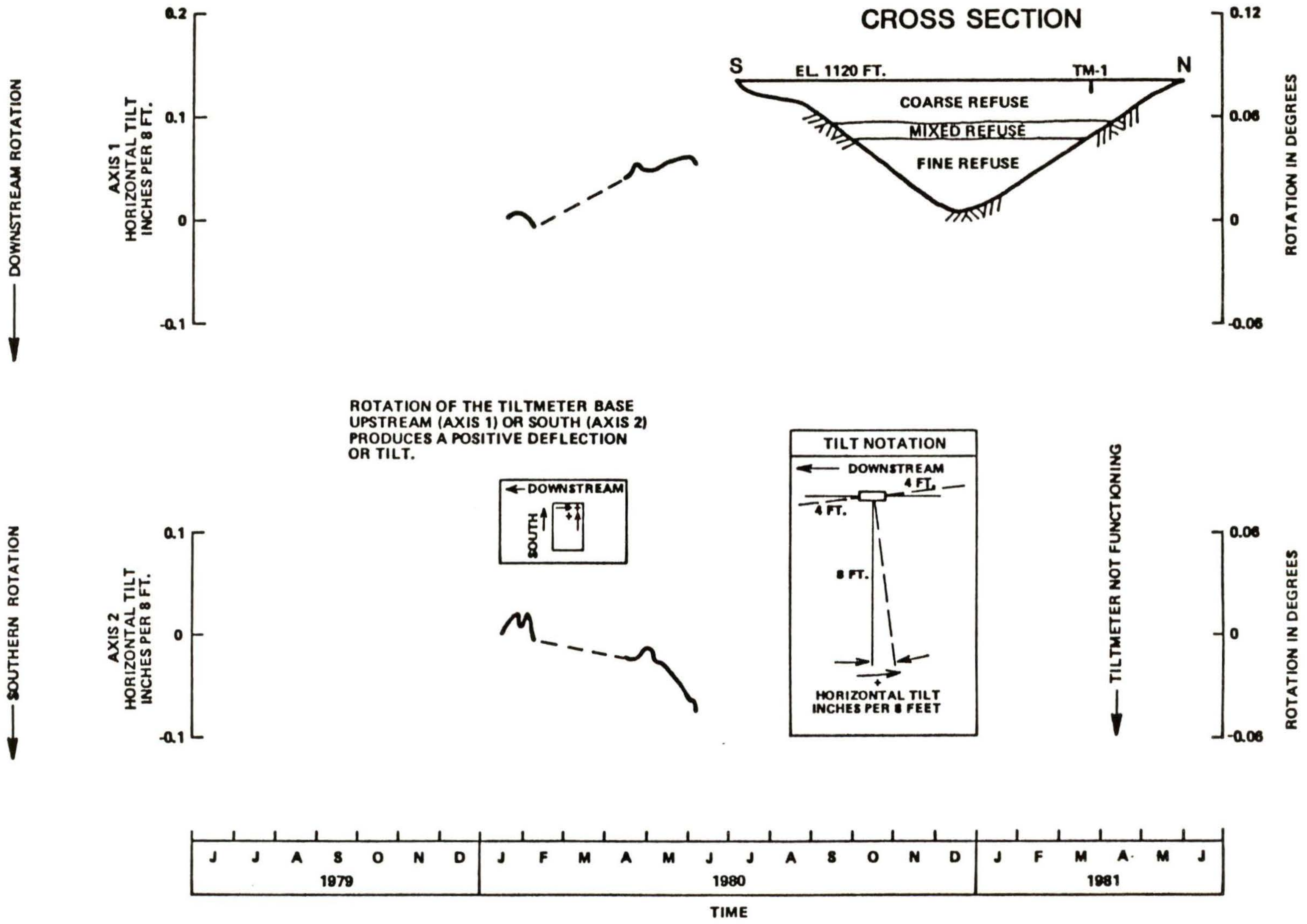


FIG. 5.7 Water Levels for Piezometer B-14



ROTATION OF THE TILTMETER BASE UPSTREAM (AXIS 1) OR SOUTH (AXIS 2) PRODUCES A POSITIVE DEFLECTION OR TILT.

FIG. 5.8 Rotation of Tiltmeter TM-1

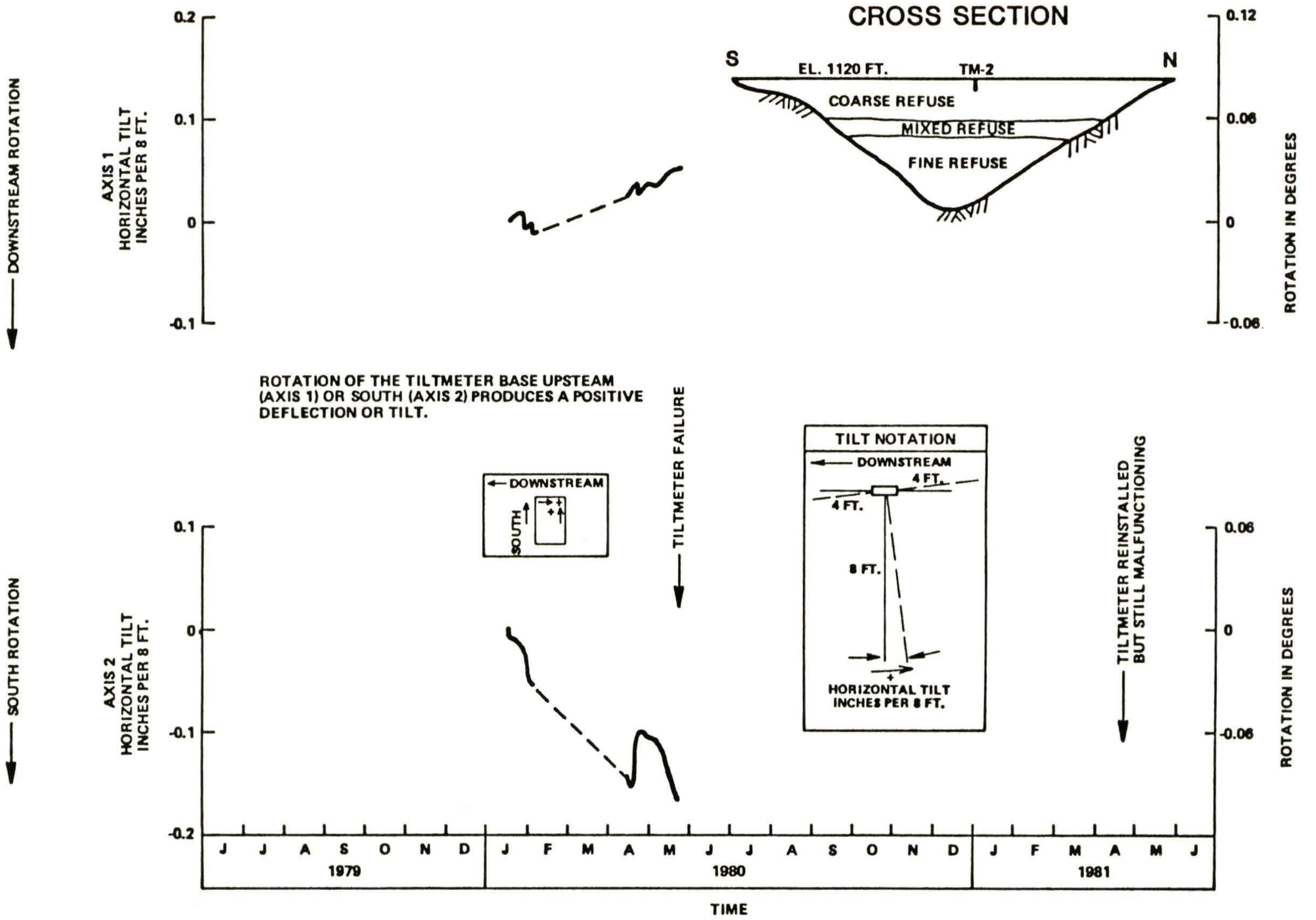
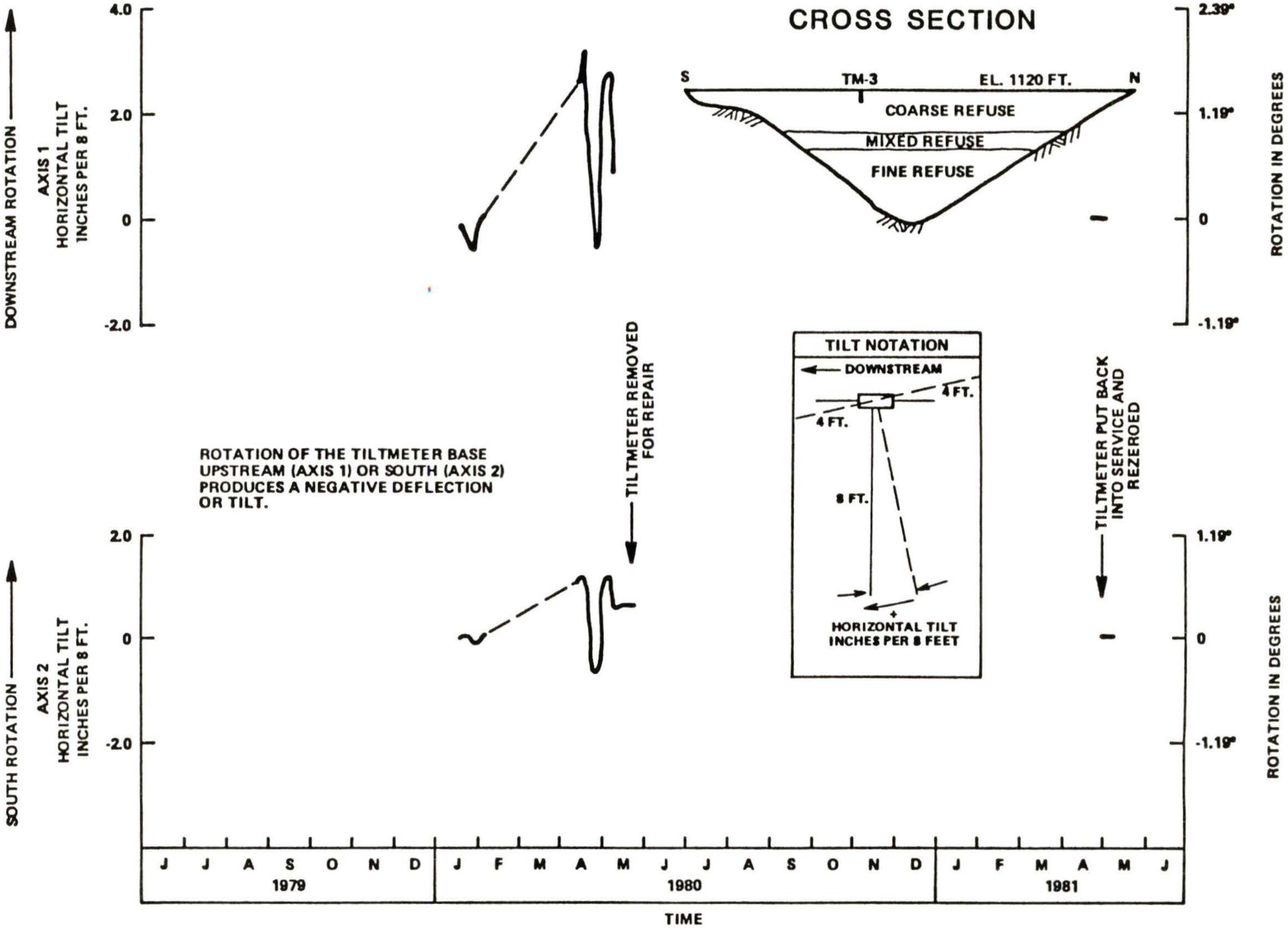


FIG. 5.9 Rotation of Tiltmeter TM-2



ROTATION OF THE TILTMETER BASE UPSTREAM (AXIS 1) OR SOUTH (AXIS 2) PRODUCES A NEGATIVE DEFLECTION OR TILT.

FIG. 5.10 Rotation of Tiltmeter TM-3

reasonable to assume that the two casings will behave similarly. The traversing probe was run in both casings a few days after casing installation to establish the initial casing positions. After the in-place inclinometer string was installed, an initial set of readings was taken and are shown in Figure 5.11. After the initial set, all data for the inclinometer sensors were recorded as changes in horizontal deflection either upstream or downstream.

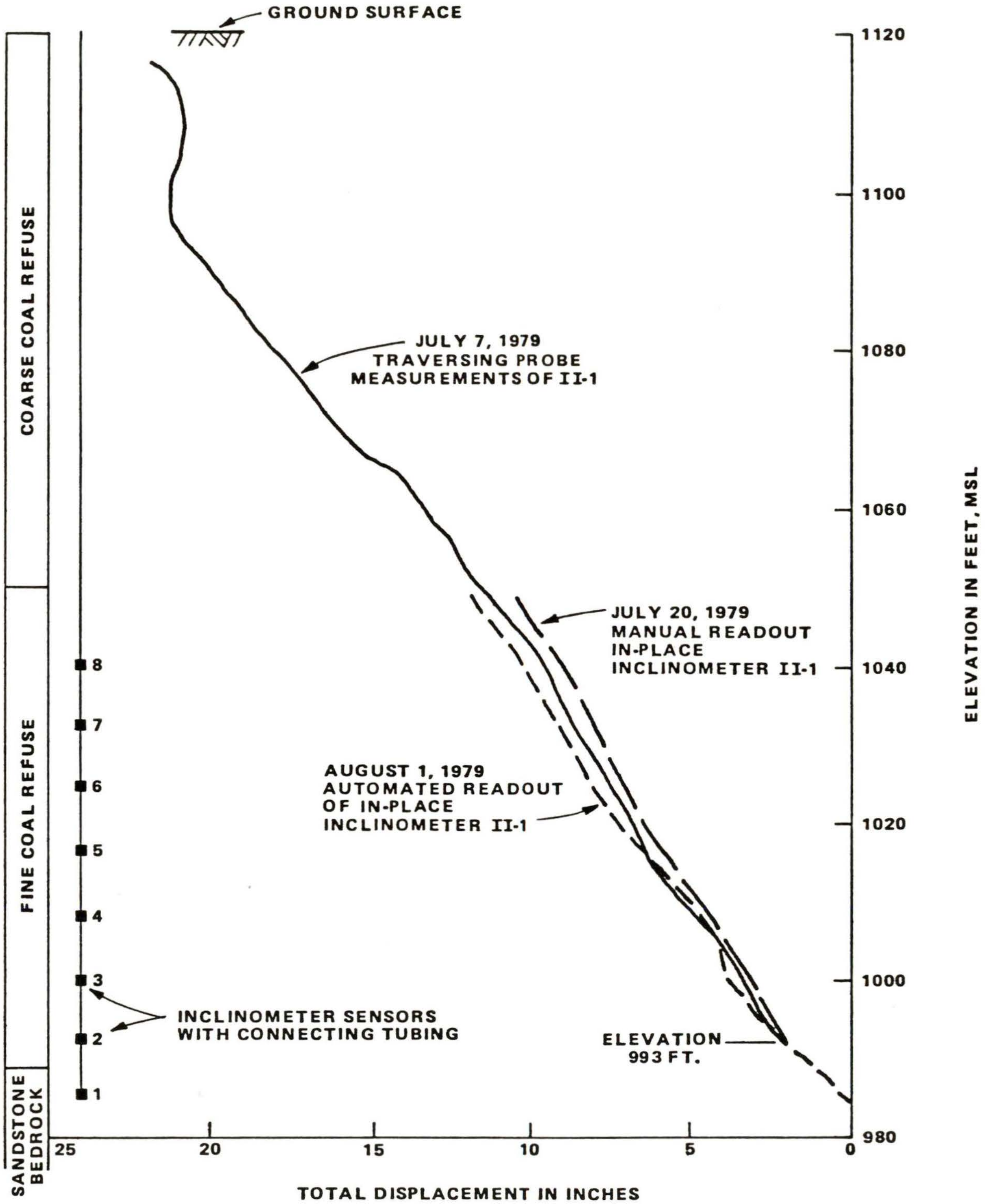
In May 1981 the TI-1 casing was resurveyed with the portable probe inclinometer to record deformations which had occurred in two years since installation. These deformations are shown in Figure 5.12 and add up to a maximum downstream movement of approximately 1.15 inches near the interface between the coarse coal refuse and fine coal refuse. Also shown on Figure 5.12 is the accumulated measured change in deformation for that part of TI-1 casing in which the in-place inclinometer string was installed. This accumulated in-place inclinometer deformation agrees closely with the measured change in the nearby casing, which suggests that the measured deformation accurately represents true movement within the embankment.

One inclinometer sensor (sensor #1) showed a very erratic reading after installation, which suggests a faulty sensor, so that the output of this sensor was not included in Figure 5.11. However, the total deformation change recorded for this sensor between the initial reading and the final reading in May 1981 was quite reasonable, and is included in Figure 5.12. This sensor did show some erratic output at various times in the monitoring period and care was required in interpreting the data. The cumulative displacements of individual sensors are shown as a function of time on Figure 5.13 and 5.14. Except for some temporary electrical drift which affected all sensors and which occurred in January and February, 1980, sensors #2 through #8 performed quite well.

5.1.5 Borehole Extensometers

Data from the extensometers are recorded in the field as movement of anchor points relative to the reference head located at the ground surface. However, the ground surface settles relative to the embankment foundation (bedrock), and thus we have recalculated the movements with reference to the bedrock anchor at each extensometer location. The data for each of the three extensometers are shown in Figures 5.15, 5.16 and 5.17. The movements of each anchor point relative to bedrock are plotted. At each of the three extensometer locations, the ground surface settled between 0.75 and 1.0 inch during the 15-month monitoring period. The extensometer installations were not completed until January 1980 due to the delay in delivery of the data logger, and thus the measured settlements are probably only a part of the total settlement that occurred since July 1979. In most cases the linear potentiometers were quite steady between daily readings. A precision of between 0.002 and 0.003 inch was quite common. The fluctuations apparent at the last field period, April 1981, are the result of removing and resetting the potentiometers for manual readings.

Manual readings of the extensometer, using a small metal scale, were performed in January 1980 and May 1981 to check the reliability of the electrical readings. These readings are plotted on the same figures as the automatic readings. Except for the anchors in the middle of the fine refuse and at the fine/coarse refuse interface on MPBX-1, the mechanical readings are very close to the electrical readings. On these two anchors the difference in readings is probably due to inaccuracies in the mechanical reading rather than the potentiometers. MPBX-2 and



NOTE: NO. 1 SENSOR NOT USED IN TOTAL DISPLACEMENT CALCULATIONS DUE TO ERRATIC READING. DISPLACEMENT OF BOTTOM 8 FEET ASSUMED FROM TRAVERSING PROBE.

FIG. 5.11 Initial Inclinometer Casing Positions

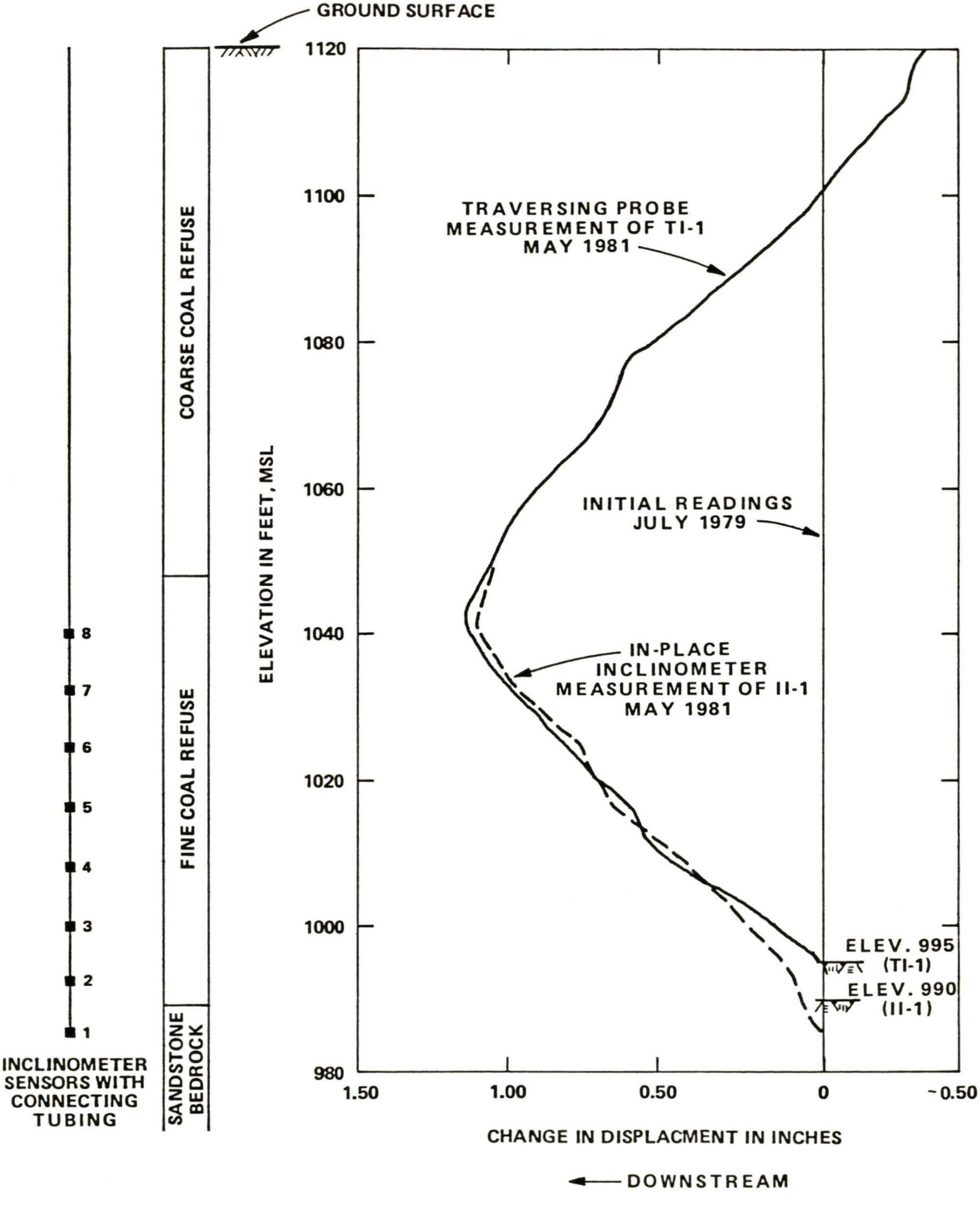


FIG. 5.12 Horizontal Deformation of Embankment Measured by Inclinometers

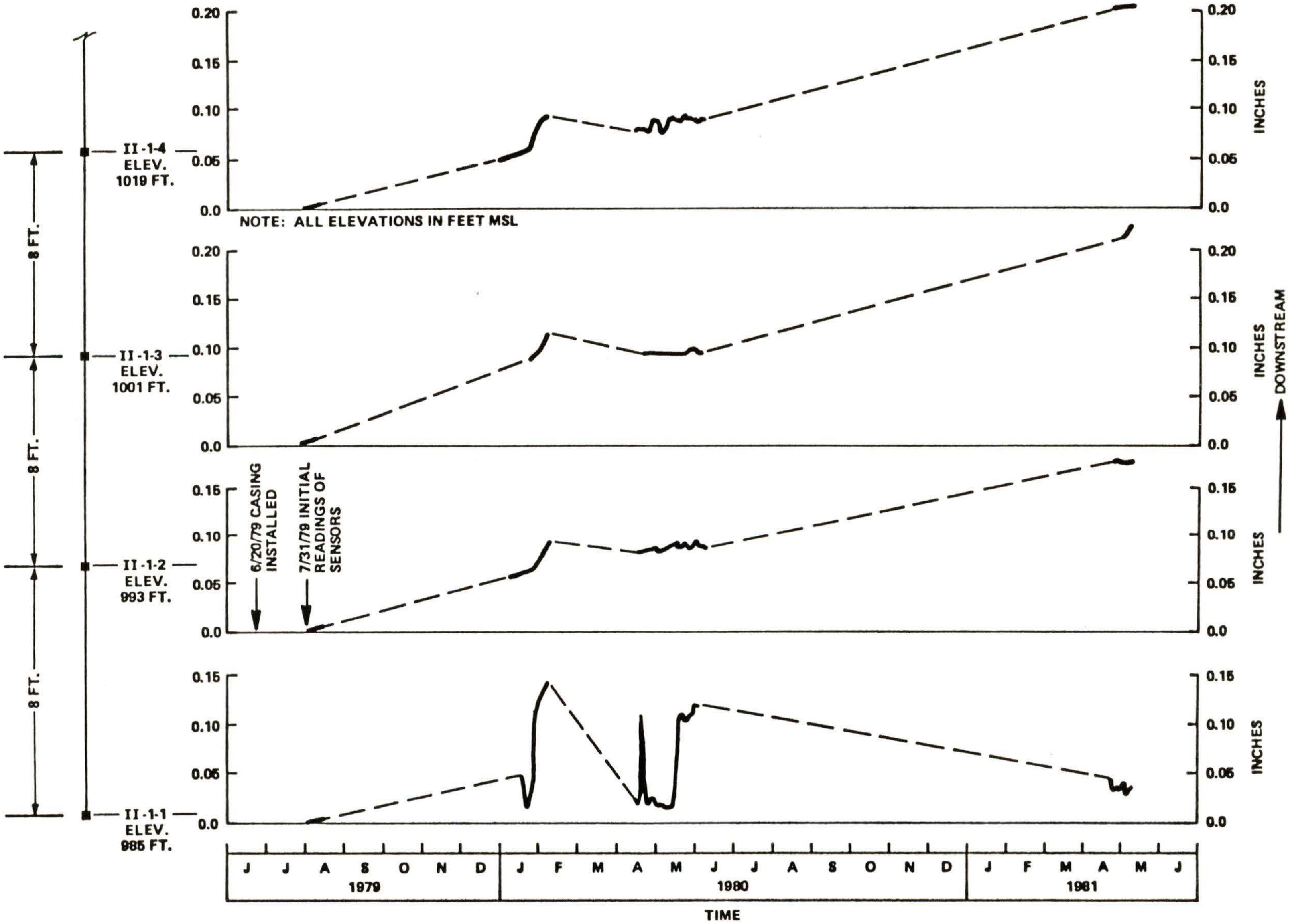


FIG. 5.13 Horizontal Deformation of Embankment Measured by In-Place Inclinometer Sensors 1, 2, 3 and 4

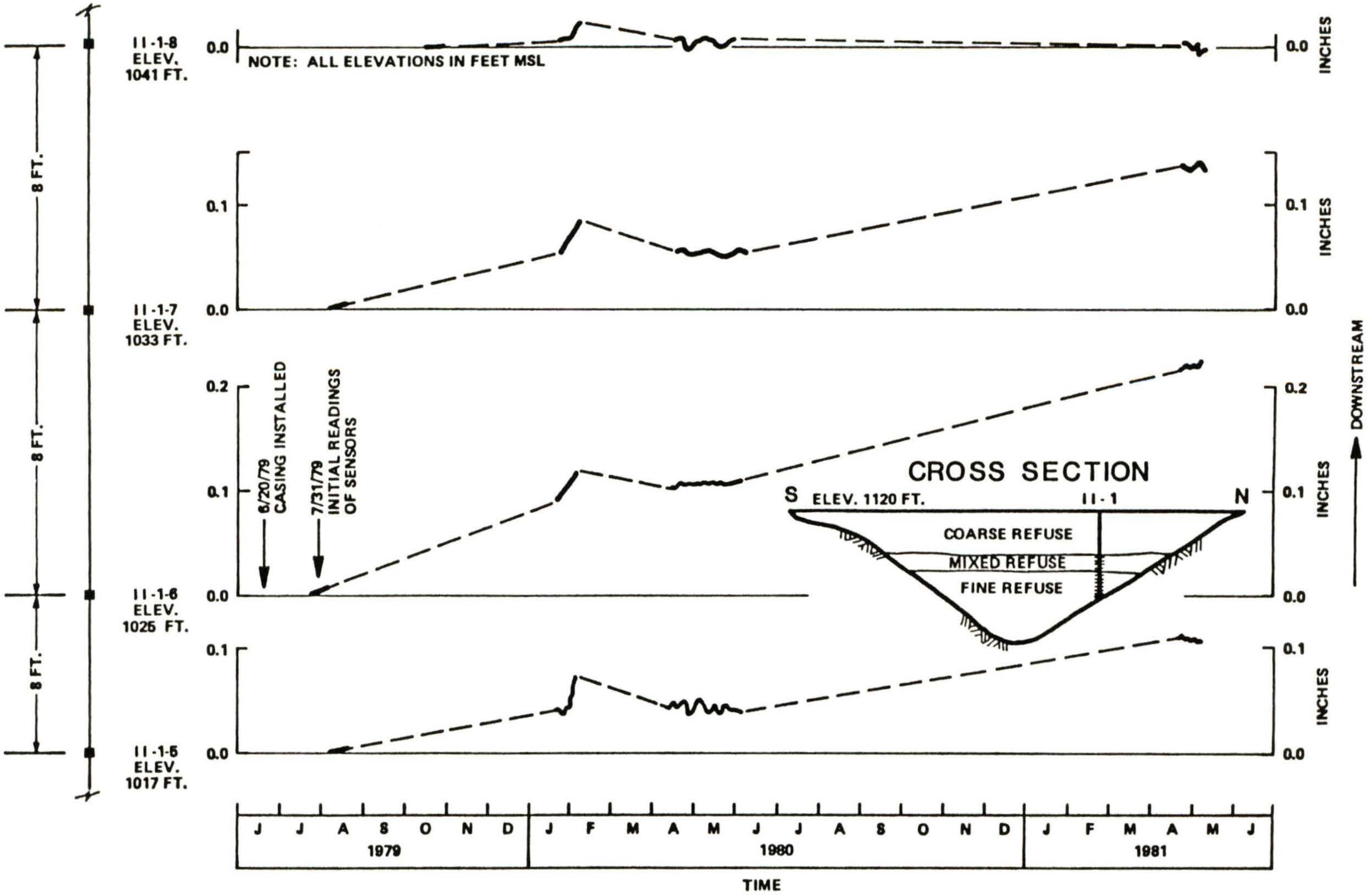


FIG. 5.14 Horizontal Deformation of Embankment Measured by In-Place Inclinometer Sensors 5, 6, 7 and 8

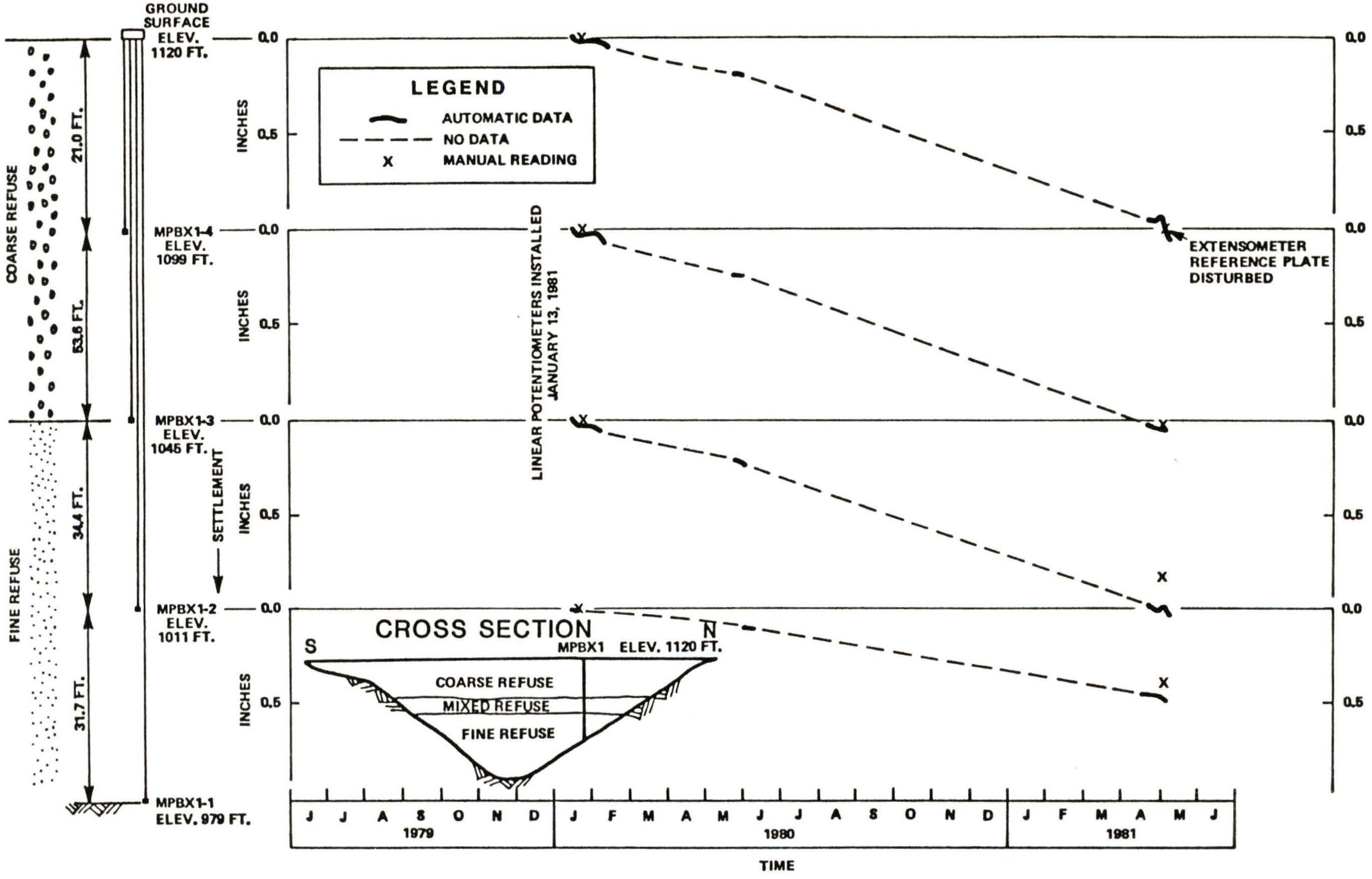


FIG. 5.15 Vertical Deformations at MPBX-1

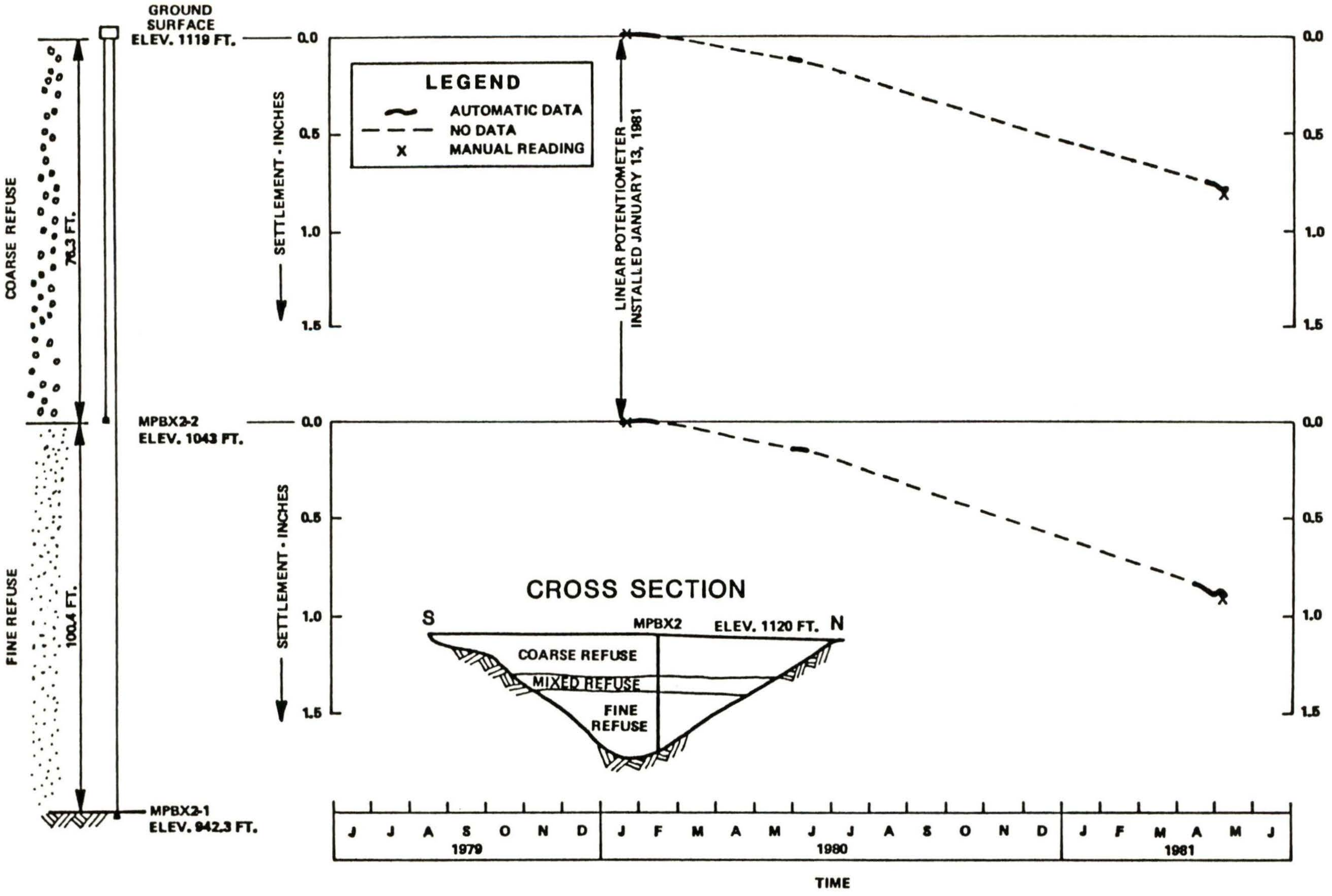


FIG. 5.16 Vertical Deformations at MPBX-2

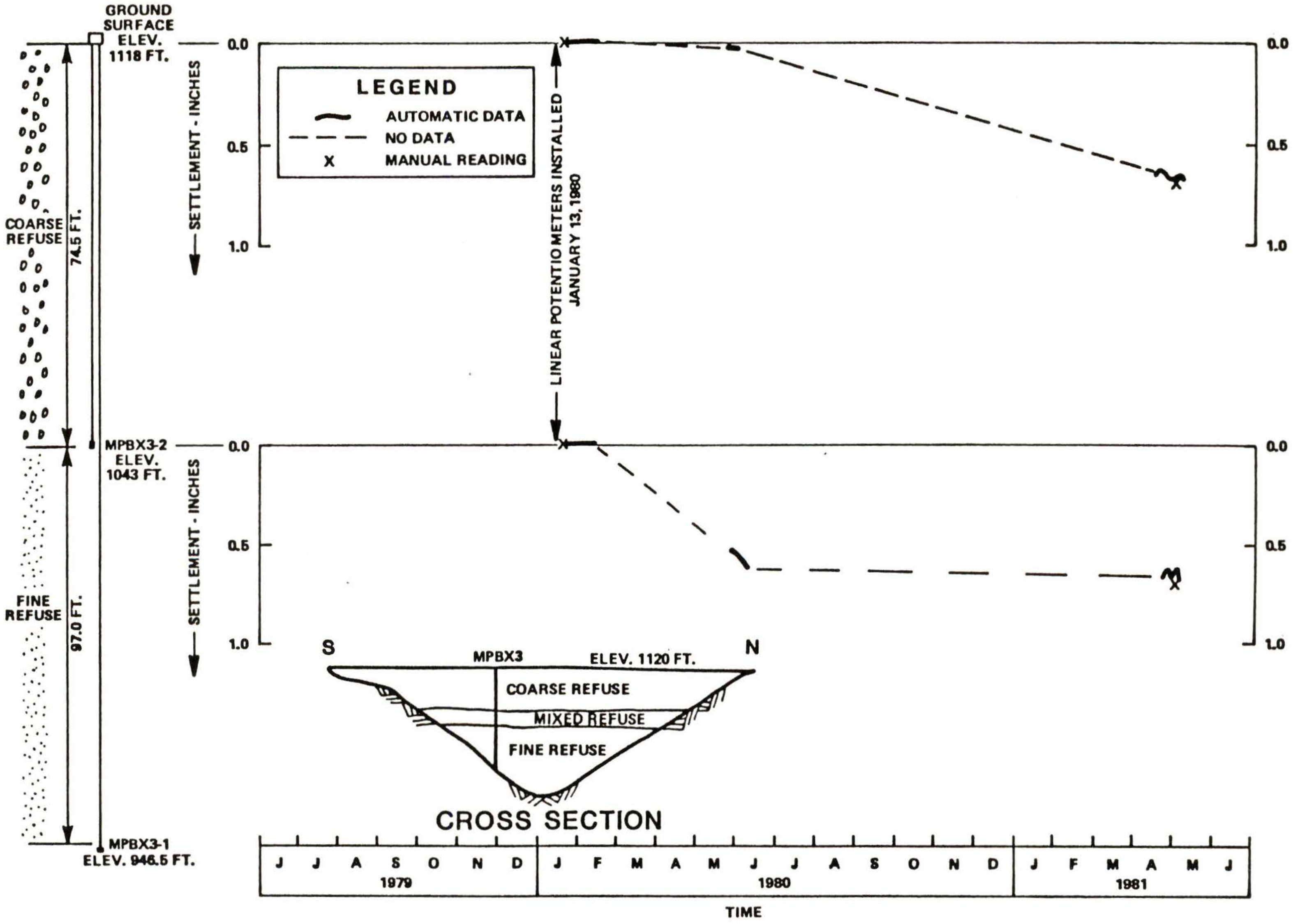


FIG. 5.17 Vertical Deformations at MPBX-3

MPBX-3 both show little or no movements of the anchor located at the interface between fine and coarse coal waste relative to the ground surface. At MPBX-1 (Figure 5.15), both the anchor at the fine-coarse refuse interface and the anchor halfway through the coarse refuse show little movement relative to ground surface. However, the anchor located within the fine refuse indicated settlement of approximately half the magnitude of that of the ground surface and other anchors. These results clearly indicate that the compacted coarse coal refuse is settling as an intact mass and that consolidation is confined to the underlying fine refuse.

5.1.6 Weir

Figure 5.18 shows the variations in seepage rate over a one-year time period between August 1979 and August 1980. The data for this graph were taken from the mechanical strip chart recorder which is a part of the Leupold & Stevens water level indicator. This data were used because it provides a more complete record than the data from the electrical sensor. Data from the final three weeks of the project, April 1981, were not available because the mechanical recorder was out of paper and the rotary potentiometer had failed. However, manual measurements of the water flowing over the weir indicated that the flow rate had not changed appreciably. Comparison of the mechanical and remote electrical measurement indicates that they are within reasonable agreement.

5.1.7 Pond Level Sensor

The pond level sensor was installed in January 1980 at the upstream end of the embankment in the fine refuse. However, the signal conditioning printed circuit board for this sensor had been damaged at an earlier time and had to be returned to Seattle. At the April 1980 field visit, the board was returned to service but the pond level sensor had been buried. The coarse waste embankment had been extended further than we had originally anticipated and the sensor covered with coarse waste. When checked electrically, the sensor did not function. Most likely, the electrical cable was stretched and broken during the filling operation. Thus, no data were collected from this sensor.

5.1.8 Meteorological Measurements

Figure 5.19 shows the cumulative precipitation for the one-year period between August 1979 and August 1980, and the monthly precipitation. As with the weir, the data were taken from the mechanical recorder because of the continuous records this device supplied. The 56 inches of rainfall measured over the one-year period is higher than the 50-inch per year average and would certainly qualify this site as a high precipitation area. It is interesting to note that the rainiest three-month period was June, July and August. Overall though, precipitation was fairly uniform over this year. Rainfall in this area is generally in the form of thundershowers with one inch of rainfall within 3 or 4 hours common. The electrical readout for precipitation agreed with the mechanical system to within the accuracy required.

Measured barometric pressure only varied slightly at this site, approximately 0.3 psi (Figure 5.20). The barometric pressure probably varied more than this during the total time period, but measurements were generally taken at the same time of day. Consequently, maximum and minimum pressures during any single day were not necessarily recorded. The record of barometric pressure is sketchy due to two failures in the electrical barometer.

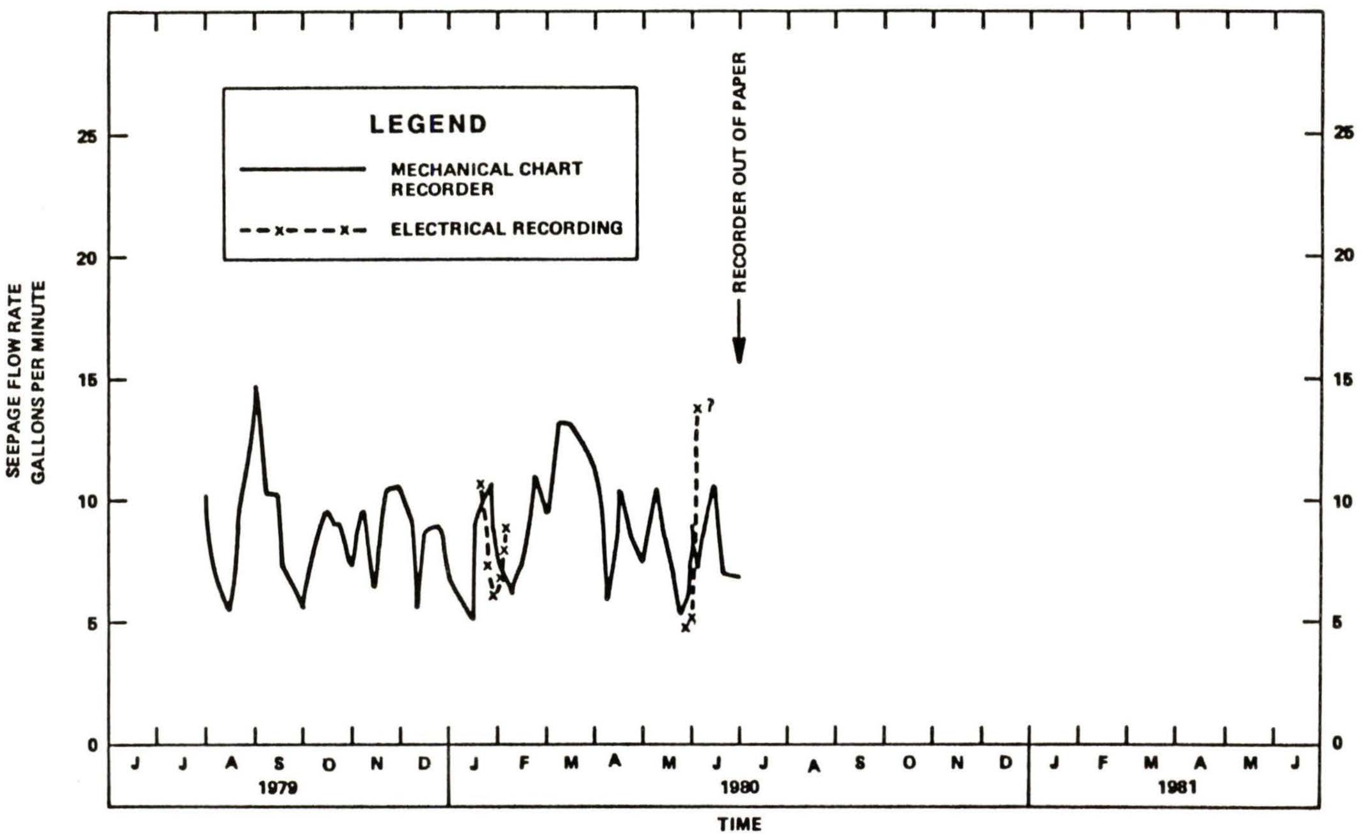


FIG. 5.18 Weir Seepage Rate

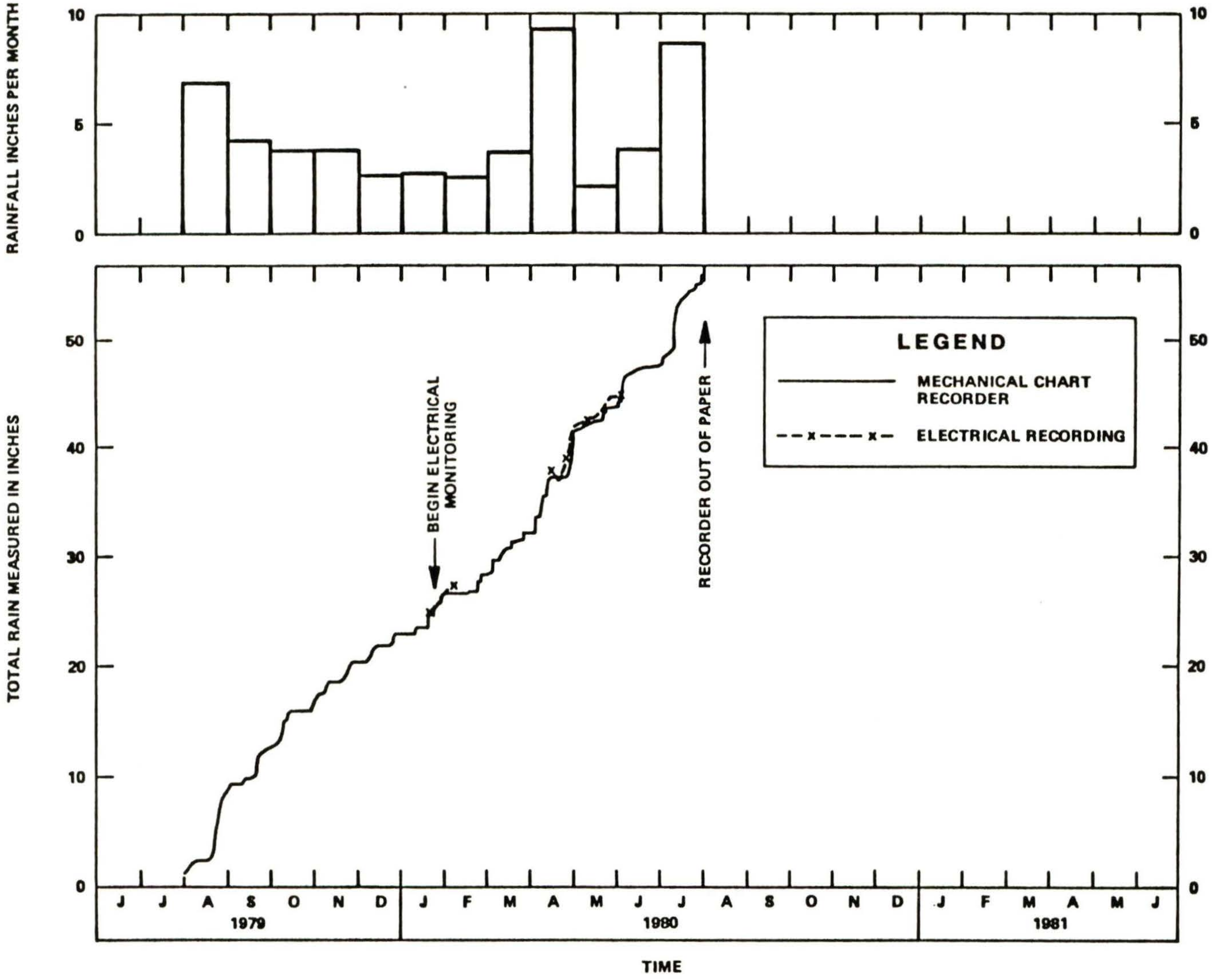


FIG. 5.19 Precipitation at Montcoal, West Virginia

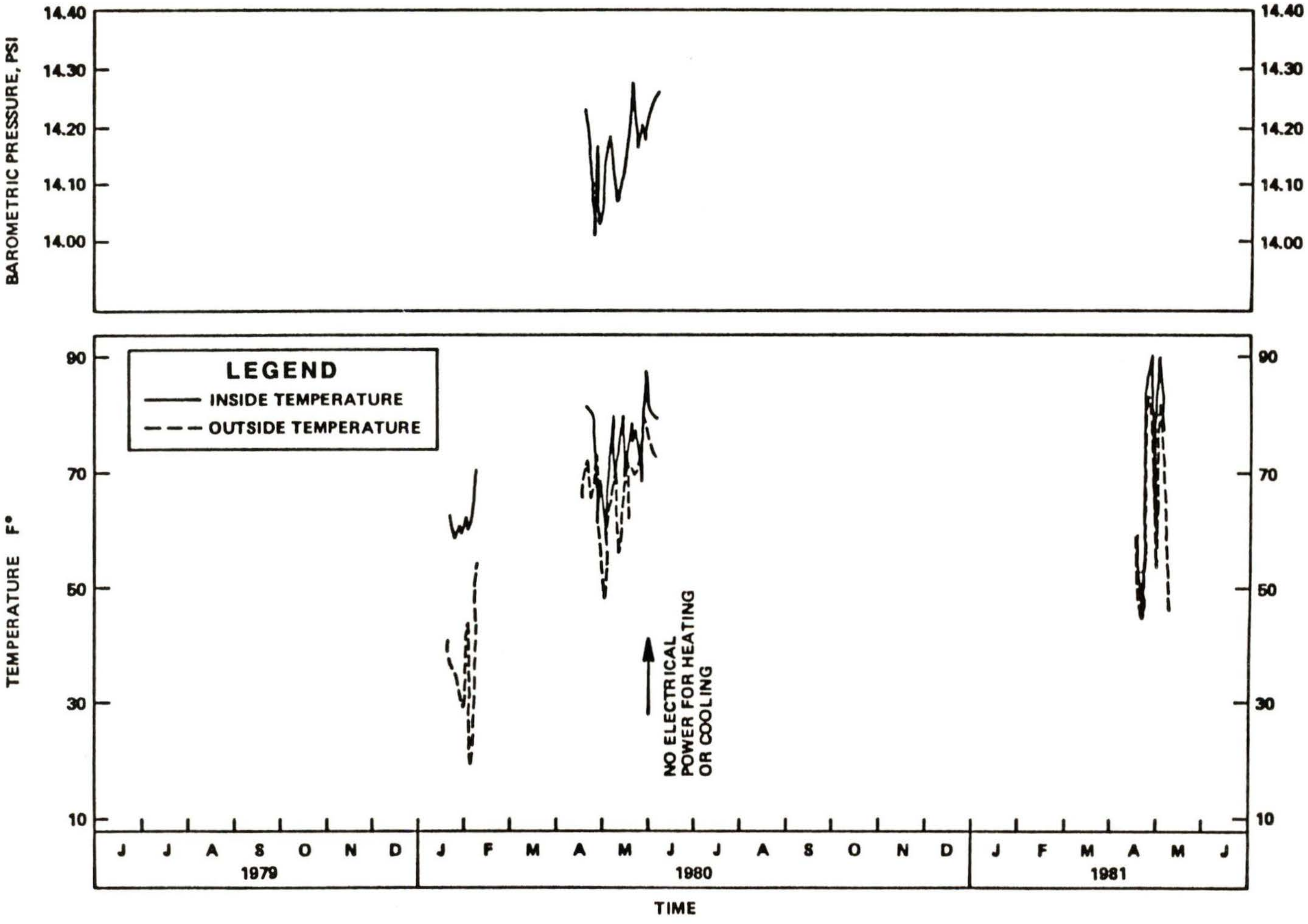


FIG. 5.20 Temperature and Barometric Changes

Measured outside air temperature (Figure 5.20) varied from 19 to 85°F, and inside the trailer air temperature varied from 48 to 91°F. during the entire field monitoring period (January 1980 to May 1981). Higher and lower ambient air temperature undoubtedly occurred, but were not measured by the automatic monitoring system because measurements were generally taken at the same time of day. Until the electrical power was cut off at the end of May 1980, air temperature within the trailer was maintained at a more constant level, 58 to 83°F.

5.2 Interpretation of Field Measurements

In Section 5.1 we have presented the collected data and documented and explained anomalous events. In this section the data are interpreted with regards to the construction of the impoundment and anticipated stability. In our opinion, most of the changes observed in the instrumentation data output since installation in 1979 are the direct result of continuing construction of the embankment. Since installation, the embankment level has been raised from approximately 1125 feet to 1175 feet, and has been extended several hundred feet upstream. The embankment has been raised by end-dumping coarse coal refuse, a durable shale mixed with coal, and then compacting it with a vibratory roller. During construction, impoundment filling continued by hydraulically pumping fine refuse behind the embankment. Between August 1979 and May 1981 the fines level was raised from approximately 1100 feet to 1119 feet elevation. The free water surface behind the embankment was rarely more than 5 feet above the level of the fines. At most times, the water did not even totally cover the fines. The unusually small quantity of water impounded can be attributed to the mine operator's successful attempt to divert surface water around the impoundment and the relatively high permeability of the fines.

All three extensometers indicate that the fines below the coarse refuse are settling by consolidation. MPBX-1's anchor within the fine refuse is showing approximately half the settlement of the anchor at the top of the fine refuse, indicating that consolidation is occurring. Consolidation is probably occurring because of the weight of increased coarse refuse which has been added.

Both the in-place inclinometer and the traversing probe inclinometer indicated that the fine refuse bulged horizontally slightly downstream. The maximum measured accumulative deflection was approximately 1.1 inch at an elevation 1043 feet, which corresponds to the interface of the fine and coarse refuse at these two boreholes. This amount of bulging is very reasonable, considering the additional 45 vertical feet of fill placed upstream. Some additional bulging will probably occur over the next two or three years as the impoundment is filled with fine refuse. However, this increase may well be less than what has already occurred.

Pore-water pressures within the embankment have remained relatively steady since installation of the piezometers. Piezometers B-12, B-13, and B-14, located along the older portion of the embankment all show piezometric levels within 15 feet of bedrock. The piezometers along the 1120-foot bench exhibit two distinct piezometric levels. For B-1, which extends to bedrock, the piezometric level is only 40 feet (elevation 985 feet) above bedrock; for the other three piezometers (B-3, B-4 and B-7) which terminate 20 to 30 feet into the fine refuse, the piezometric level is approximately at the fine-coarse coal interface (approximately elevation 1035 feet). These three shallow piezometers have shown a slight, approximately 5 feet, decrease in pore-water pressure over the monitoring period, which is probably due to extending the embankment and fine refuse discharge point upstream.

The lower pore-water pressure observed at B-1 is probably caused by the broken and jointed sandstone bedrock being more permeable than the fine refuse. This bedrock could be acting as a drain, lowering the pore-water pressure at the interface. The low pore-water pressures observed at the downstream piezometers may reflect natural groundwater rather than the effects of the impoundment. Where soil and trees have been removed from the sides of the valley, groundwater can be seen flowing from the rock. This groundwater, when constrained by the waste embankment, could raise the pore-water pressure to the elevations observed in the piezometers. Piezometric levels in all the piezometers are likely to remain near their present values throughout the remainder of embankment construction and pond filling.

Due to the diversion of the stream around the impoundment, the only source of water within the impoundment is from pumping the fines together with a small amount of runoff from the north side of the valley. Except for very large storms which exceed the diversion culvert capacity or accidental blockage of the culvert, the water within the impoundment should remain within 2 or 3 feet above the fine refuse surface. The seepage measured at the weir is probably the result of a combination of natural groundwater and the diversion ditch 100 feet south, rather than impounded water. Flow rates from this particular seep have not varied much and appear to be unrelated to the amount of water impounded. Recorded increases in flow rates appear to be related to thundershowers which increase surface water flow into the small reservoir behind the weir's bulkhead.

5.3 Instrumentation System Performance

5.3.1 General

Overall, the performance of this instrumentation system has not been entirely satisfactory. Part of the difficulty was associated with delivery delays which resulted in rushing the system into the field without having the opportunity to bench test the entire system under controlled conditions. Another part of the difficulty was associated with this particular site and its long distance from our Seattle office. Inspection, diagnosis and repair of any failure of the system required a minimum three-day trip to the site. In addition, some of the problems must be attributed to interface problems between components from different manufacturers and to the poor performance of certain signal conditioning equipment and sensors. Specific problems encountered will be described in detail in the following paragraphs.

5.3.2 Piezometers

During the monitoring period, two Irad Gage vibrating wire piezometers failed. Examination by dismantling and cutting apart one of the piezometers revealed that water had penetrated either the "O"-ring seals or the epoxy seal and attacked the coil, eventually causing a break in the connection. It appeared that the lead wires were inadequately blocked against water ingress to the gage. The second transducer was not dismantled, but it exhibited identical symptoms and it is assumed that its coil corroded also. The remaining vibrating piezometers were functioning at the conclusion of the last field trip with less than 0.5 psi zero shift.

RP-1 failed twice during the monitoring period. This piezometer was an experimental unit utilizing a Bell & Howell CEC 1000 pressure transducer in a SINCO housing. The first failure was the result of leakage past the seals. The cause of the second failure is not precisely known, but the pressure transducer is the part that failed.

RP-2, a Senso-Metric semiconductor sensor in a housing built by Slope Indicator Co., showed approximately 2 psi zero shift when checked on the last field trip. However, this shift may, in part, be due to the two repairs performed on the signal conditioning for this instrument. This piezometer has performed quite well throughout the project, with no indication of long-term drift. Data for this piezometer, Figure 5.4, were confirmed by manual water level readings at several different times.

5.3.3 Tiltmeters

All three tiltmeters failed at one time or another during the monitoring period. TM-1 lasted until the final field trip, April 1981, but, at that time the tiltmeter was not functioning, although the reason is not known. TM-2 began exhibiting erratic results during 1980 and was returned to the manufacturer, but the problem was not located. After returning the unit to service another problem was encountered but later disappeared. TM-3 began to drift during 1980 and was removed and returned to the manufacturer in May 1980. A faulty capacitor was found and replaced and the unit was returned to service in April 1981. In addition to the sensors, nearly all the tiltmeter voltage regulators located in the junction boxes along the 1120-foot bench were found to be faulty. These are the same type of integrated circuit used with the inclinometers.

5.3.4 Inclinometers

The traversing probe inclinometer casing has remained operational throughout the monitoring period. The in-place inclinometers have generally performed well throughout the project with the exception of a period in January-February 1980 when each sensor indicated a downstream movement which later reversed itself. It is very unlikely that the embankment movement is actually reversing direction. More likely, some type of electrical drift of the sensors or other external influence was affecting the sensors. A few voltage regulator integrated circuits located at the junction box near the top of the casing have failed. These integrated circuits probably failed due to humidity and temperature conditions within the junction box. Once the sensor had been switched on long enough to stabilize temperature, each inclinometer sensor except #1 exhibited a repeatability of approximately 0.002 inch.

5.3.5 Borehole Extensometers

The extensometers including the linear potentiometers and rods have performed well with no failures to date. Prior to installing the linear potentiometers there was difficulty with sealing the reference head base at ground surface, but a small amount of Portland cement grout resolved this problem. Resolution of the linear potentiometers was about 0.001 inch, which is well within an acceptable range for this type of instrumentation and more than adequate for this measurement.

5.3.6 Weir

The bulkhead and notched plate performed well during the monitoring period. The plywood used to build the bulkhead and notched plate was beginning to rot by the end of the project but was still functioning. The plywood would probably survive another year or two with remedial repair, but a permanent, long-term weir should be constructed from concrete or steel if the project is extended much further. The mechanical water level recorder worked well, but the rotary potentiometer which is the electrical sensor for this instrument failed some time before the last field trip (April 1981). In addition, some of the conductors of the connecting cable are broken. Replacement of the potentiometer should not be very difficult or expensive. The original potentiometer probably failed due to humid or freezing weather. Cause of the cable failure is not known since no visual signs of breakage were observed.

5.3.7 Pond Level Sensor

The pond level sensor was destroyed by construction activity in April 1980. The instrument would have probably functioned as designed if it had been located much further upstream. However, considerably more electrical cable would have been necessary to locate the sensor further upstream and the cable could not have been buried, but would have had to be laid unprotected on the ground or strung from trees.

5.3.8 Meteorological Measurements

Some time during the second winter in the monitoring period, the water in the rain collecting tube froze and split the tube. The tube was repaired at the last field trip and no other problems occurred with the precipitation device. The Stevens water level device is reliable and quite suitable for automatic long-term precipitation measurement, but future projects should use some type of antifreeze to prevent freezing of the collected water.

The type "T" thermocouples used to measure indoor and outside air temperature also worked well and were still functioning at the end of the monitoring period. The barometer failed twice during the monitoring time. The first failure evidently occurred due to a faulty quartz sensor and was repaired by the manufacturer between January and April 1980. The second failure was discovered at the last field trip, however the cause has not yet been discovered. We are not certain whether this was just a particularly bad unit or whether this brand of sensor is plagued with problems.

5.3.9 Power Conditioning Equipment

The power conditioning equipment was selected to provide steady, regulated 120 VAC power for the various electronics equipment. The initially designed system utilized a special power regulator and lightning protection device built by Slope Indicator Co. expressly for this project along with a standard Sola power conditioner. During the field trials it became evident that transient voltages large enough to trigger the gas discharge lightning arrestor in the Slope Indicator Co. unit were occurring. When the lightning arrestor is set off, the circuit breaker for the trailer is tripped, which requires manual resetting. To avoid resetting the circuit breaker a higher capacity gas discharge tube was installed. Since the electronics of the signal conditioning units were being repeatedly damaged at that time it was considered possible that these transients were not being totally arrested by the Sola conditioner. Following power line switchoff, a portable motor generator was brought in to provide electrical power for the instruments. The high transient voltage problem appeared to be intensified and it was decided to purchase and install an additional power conditioner, a Topaz Line 2 Model 70301, in series with the other conditioners to try to eliminate the problem of transients.

5.3.10 Signal Conditioning

Signal conditioning and electrical power for the instruments was supplied by two units, the Slope Indicator Co. electro/piezo signal conditioner and the Irad MB-6 and switchbox. Both of these units failed more than once and have caused continuous problems. The Slope Indicator Co. unit failed sometime between August 1979 and January 1980, with most of the integrated circuits in the unit being destroyed. The unit failed a second time in June 1980. The exact causes of both failures are not known, but a combination of too high a supply voltage, AC line transients and overheating were concluded to be the most probable causes. It appears that the unit was designed to operate at 18 volts, whereas most of the components are designed to be safely operated at 12 to 15 volts. The power supply was subsequently modified to operate at 15 volts to try to reduce these problems. A one-month checkout in Seattle and the last field visit did not uncover any additional problems.

The Irad switchbox failed three times. Fortunately, only the vibrating wire piezometers were used with this equipment. The unit was installed in January 1980 and broke down in February 1980. The unit was repaired at the factory, placed in service in May 1980 and failed again after two days. The unit was again repaired, tested for one month in Seattle, and placed back into service in April 1981, and then promptly failed again. The cause of this problem was not determined. A completely modified unit should be designed if this type of instrument is to be used in future remote monitoring systems.

5.3.11 Data Logger and Communications Equipment

The only difficulties associated with the Acurex Autodata 9 data logger were delayed receipt of the instrument and having modifications performed incorrectly. Although we ordered the data logger in early May 1979, we did not receive the complete shipment from Acurex until December 1979 despite many assurances to the contrary. The modification for interfacing the digital data from the Irad equipment worked well, but the modification for the autodialer and modem did not function as we had originally designed and requested it. The data logger was to have been programmed to continuously scan the channels for preprogrammed alarm limits. At periodic intervals and whenever alarm conditions were encountered, the logger would activate the autodialer and telephone our computer. This mode of operation was never realized due to incompatibility problems among the autodialer, modem and data logger interface. First, the relay, which was to close and activate the autodialer on either an alarm condition or at periodic intervals, only activated on an alarm situation, not periodically. Secondly, this relay, which was added to a standard printed circuit board, was triggered at random times by what appeared to be electrical interference, thus setting off the autodialer. Thirdly, the autodialer and modem were not compatible. For these reasons the autodial-out concept was dropped early in the monitoring trials. The modem and data logger were connected by the standard RS-232 interface and the system set up to operate in the auto-answer mode. When the data logger and modem were first installed in January 1980, the modem was damaged and had to be returned for repair. While the modem was being repaired, the data logger was programmed to interrogate the sensor at a selected interval and print the data out. Once the modem was returned to service in April 1980, data was recovered by calling the site periodically from Seattle.

The request for the telephone line was initiated in early June 1979, and installation was not completed until October 1979. This delay was apparently primarily associated with obtaining permission to cross the railroad track. Several times during the monitoring period, the telephone line to the trailer was knocked down by a train. However, within two days of discovering the breaks, the line was repaired by the telephone company. While aggravating to have the telephone line knocked out, other more severe difficulties with the electrical power tended to minimize the impact of no telephone service.

A special note should be made of the flexibility of the junction boxes for maintenance and repair of the equipment. Each screw terminal was labeled and a schematic provided by Slope Indicator Co. Labeling the terminals allowed rapid field testing of cable continuity and individual sensors. The importance of rapid identification of individual conductors in a large buried cable was clearly demonstrated during repair of the broken cables in April 1981.

6.0 COMPARISON OF SELECTED INSTRUMENTATION SYSTEM WITH OTHER SYSTEMS

6.1 Automatic Data Acquisition Systems in General

In this section four other remote geotechnical monitoring systems installed in the last few years which are comparable to our project are discussed. The pertinent characteristics of these four systems are explained and compared to this project's requirements and restrictions. These other systems are all related to large impoundment structures or to surface mine-related projects in North America. A literature search failed to locate any other remotely monitored coal waste impoundments and were thus forced to utilize other examples for comparison purposes. Shannon & Wilson has been directly involved with two of the projects and information on the other two systems was obtained from published literature. Very few remote or automated geotechnical monitoring systems are currently described in published papers, and as a consequence, written information on this subject is very limited. Most previous large geotechnical instrumentation projects have utilized manually read instruments. One reason for the lack of use and of information on ADAS is the variety of skills involved in designing a project which utilizes ADAS and the degree of sophistication of the system. A single person or organization will generally have limited knowledge of all facets of the system.

A system was developed by CANMET (Larocque, 1977) to demonstrate remote monitoring of geotechnical instruments in an open pit mine. This system was discussed briefly in Section 3.4 as a simple, remotely monitored site. Data transmission was primarily by radio telemetry, although telephone lines were used from the relay station back to a university. Although many instruments are discussed in terms of radio telemetry, the field trials included only a single multi-position borehole extensometer. This borehole extensometer had five different sensors of both analog and digital design. This system was not totally automated and required a human to initiate interrogation of the instruments. From the mine base station which initiated interrogation, the data were relayed through dial-up telephone lines to a storage unit and then from the storage unit to a computer. This system demonstrated that many types of available sensors could be included or modified to be included in a remote monitoring system. Great detail was presented in the discussion, including schematics, model numbers of equipment, and instructions for construction. A drawback to this system was that many of the interfacing electronic circuits were custom-made for this project and are not commercially available. In addition, the sensors were limited to displacement transducers and did not include servo-accelerometers, resistance piezometers, or other transducers which might be required in slope stability monitoring.

Comparing this system to our present project, there are a number of features which make the CANMET system unattractive. First, the number of types of sensors is too small to adequately measure the many varied parameters in a coal waste impoundment. If borehole extensometers were the only instruments used at a site, this system would be very useful, but most impoundments will require additional types of sensors. Second, specialized technical labor would be required to build another of these systems since additional custom-built electronics are required in addition to assembly line components. Third, the system is not totally automated and requires an individual at the base station. The major advantage of the CANMET system over our present system is that neither power nor telephone lines were required in the immediate vicinity of the instruments, particularly important in an open-pit mine working environment. Batteries were utilized to power the electrical equipment and heat the enclosure. VHF radio transmission of data eliminated the need for long electrical signal cables.

A second remote monitoring system was discussed earlier and represents a system more similar to the present project than the CANMET system. The second system is that developed for a feeder canal at Grand Coulee Dam (Bailey, 1980). On this particular project, 123 in-place inclinometer sensors (servo-accelerometers) were monitored using an Acurex Autodata 9 data logger. The purpose of the installation was to continuously monitor a large soil slide adjacent to the feeder canal. All sensors were monitored for indication of movement on a continuous basis and an alarm set off if preselected limits were reached. Data were stored on 9-track magnetic tape for off-site analysis. This system was used to monitor a large number of sensors from a central data collection office. The major difference between the present and the Grand Coulee systems is that the coal waste impoundment monitoring system requires many different instrument types, whereas Grand Coulee used only one. In addition, our system transmitted data over telephone lines to a far distant data processing center, whereas the Grand Coulee system did not, although it could be easily modifed to do so. The continuous monitoring/alarm feature of the Grand Coulee ADAS might be particularly useful at a site where the coal waste impoundment was known to be unstable and had to be carefully monitored during construction.

The third monitoring system was completed in 1972 and is located in Montana (SINCO, 1974). This ADAS was developed to monitor the left bank of Lake Koocanusa which is the impounded reservoir of Libby Dam. The left bank is a potentially unstable rock hillside which threatened to cause flooding downstream. The Libby remote monitoring system has several attributes which are pertinent for coal waste impoundment monitoring. The sensors included at Libby were multiple-position borehole extensometers (136 sensors), vibrating wire piezometers, and rock noise (acoustic emission) transducers (4 sensors). The monitoring console was semi-automatic with data recorded on punched tape. The data were then manually transmitted back to a computer in Portland through a teletypewriter and telephone lines. At this site, access to boreholes was very difficult, particularly in winter, and the remote monitoring capabilities became very important.

Disadvantages of this system are that it is only partially automated and was custom-built for this site. The system is now nearly 10 years old, and much of the electronic monitoring system is out-of-date. As in most field instrumentation programs, there were problems with some instruments. At Libby an electrical storm destroyed several electrical piezometers because of insufficient lightning protection along the cables. The acoustic emission monitoring system was not very useful due to extraneous electrical interference. The equipment in this portion of the system did not malfunction, but the use of acoustic emission does not as yet lend itself well to automatic monitoring for slope stability. The remainder of the system has worked successfully since installation in 1972. It should be recognized that all of the on-site data recording equipment is housed in a permanent structure within the dam and is tended by full-time skilled maintenance staff who inspect the equipment on a day to day basis.

A 100-channel remote monitoring system is currently being installed for Locks and Dam No. 26 (Replacement) on the Mississippi River. The remotely monitored instrumentation includes piezometers, barometer and tiltmeters. Besides these instruments, the ADAS is designed to be flexible enough to also monitor instruments yet to be designed on two future phases of construction at the same site. The ADAS is designed to perform all data reduction and processing at the site and be remotely interrogatable by telephone. Due to the extreme nature of the ADAS requirements, a minicomputer, an HP-1000L, will be employed, housed in a climate-controlled room with a telephone line and conditioned electrical power. In addition to the minicomputer, peripheral devices such as a line printer, graphics terminal, magnetic disk mass storage units and telephone modems will be utilized for data processing and storage. Data logger/controllers are used to collect data from various instruments rather than simple data loggers because these units are more versatile and can be connected in parallel. The logger/controllers are located on various monoliths close to the instruments. A parallel bus system connects the logger/controllers and minicomputer that provides flexibility for future expansion. The interconnection between the minicomputer and logger/controller will be by fiber optic cable to reduce or limit the damage caused by lightning or electrical transients.

The Locks and Dam No. 26 ADAS probably represents the state of the art in automatic monitoring for geotechnical parameters using available mass produced electronic equipment. There are some advantages in the system for long-term unattended monitoring. First, the sophisticated data processing which the minicomputer provides can provide alarm monitoring as well as to modify monitoring frequency automatically. Second, the sophisticated processing also permits displaying pertinent information in an easily understandable format to technicians who are unable to interpret manual instrument readings or simple voltage levels.

The disadvantages of this system for use at a coal waste impoundment are the environmental requirements for the electronic equipment, the high electrical power and telephone line requirements and, last but not least, the need for day to day inspection and maintenance of such a complex system by skilled personnel. The sophistication of such an ADAS and its cost may not be justified unless several impoundments can be monitored by a single ADAS. While only three types of instruments are to be monitored at Locks and Dam No. 26 during this phase, the logger/controllers in this system are very versatile and can monitor servo-accelerometers, electric resistance strain gages, digital data, resistance changes and frequency changes. This type of equipment may be very useful in the future if it can be improved to reduce the power requirement and extend the range of temperature and humidity in which it can function.

6.2 Improvements in Instrumentation System at the Selected Site

As in many research projects, there are several areas of improvement which could be made in future monitoring at Montcoal. The weak points of the present system become more apparent the longer the monitoring period and as unforeseen problems arise. The single most important improvement would be a reliable, clean power supply. Many of the problems associated with electronic equipment may be partially caused by the power supply. Electrical power from mine sources are notoriously poor with voltage spikes and outages common. The other major improvement needed is in the signal conditioning equipment which had a history of failure. This equipment is particularly important since almost all the sensors are influenced by this equipment. In general, this equipment should be designed to be more durable, have increased environmental operating range and lower power consumption.

Sensor placement has been adequate in most cases although the pond level sensor was located too close to the construction area. Great care must be taken to keep sensors and cable away from active construction areas or additional protection against mechanical damage added. The design of the pond level sensor needs to be improved and its location revised to prevent damage. In some cases, instruments are redundant and could be eliminated without major loss of data.

Certain types of sensors should be improved where possible or eliminated. The vibrating wire piezometers and their associated readout equipment, in particular, need to be redesigned and improved before being incorporated into an ADAS or they should be replaced with another type of electrical piezometer.

An improvement needs to be made to automate the transmission of data from the site to a central processing station. We attempted in this project to improvise an automatic dial-up of our computer in Seattle for periodic data transfers over the telephone but complications due to both hardware and software problems prevented this. If the total system could be modified so that dial-up of the site and an interrogation command was initiated from the central processing computer, data monitoring labor costs could be reduced. Our Seattle computer would require major hardware and significant software modification to perform this function but other models of computers are commercially available which could be utilized with less modification.

6.3 General Systems for Coal Waste Impoundments

Designing a general instrumentation system, either remote or manual, for a coal waste impoundment is very difficult because each site is unique. Size of embankment, construction material, foundation conditions and original topography will have a great influence on the significant parameters to be measured as well as the number and location of individual instruments or sensors. The choice of instrumentation for a particular site should be made by a professional engineer familiar with the site and, most importantly, experienced in the design and application of instrumentation of large earth embankments.

Some parameters will very likely need to be monitored at a majority of impoundments and the relative number of individual sensors can be estimated. Those parameters which might reasonably be monitored at each impoundment include: rainfall, impoundment water level and subsurface pore water pressure. Parameters which might be measured at one site but not another include: vertical deformation, horizontal deformation, seepage, surface settlement and surface tilt. The minimum number of individual sensors for a site would likely be 6 and the maximum number for a site might be 20. Of course, a site showing obvious signs of distress might require a significant increase in the number of sensors as might an unusually large impoundment or one of unusual and novel design. If a prototype general remote monitoring system is designed, it should be flexible enough to accept several of the common geotechnical instruments with a capacity of 6 to 12 individual instruments or sensors. Many of the instruments which could be used to measure these parameters were utilized in this project. Some of the general sensors which could be interfaced with this type of system might include potentiometers, servo-accelometers, and variable resistance type devices. Should a number of those remote monitoring systems be implemented throughout the U.S.A., geotechnical instrument manufacturers would begin to offer options to their equipment to interface directly to the data collection portion of the system.

Our current project used dial-up telephone lines to transmit data across country to a central computer. However, several other data transmission methods are available to accommodate general systems for impoundment monitoring as discussed in Section 3.5. The exact method used for an individual site would depend on several variables such as distance from public communication lines, topography, geographical location, electrical interference, etc. Satellite relaying of the data through GOES probably represents the most versatile and economic method for a large number of sites geographically dispersed. Thus, a general remote monitoring system should ideally have the technical capability to be interfaced to a GOES compatable radio transmitter.

6.4 Costs Associated with Selected System

As a part of this project, careful records of the instrumentation costs were kept to permit comparison of the cost of this system with other systems. The costs were separated into five categories: 1) system design, 2) capital equipment, 3) installation, including subcontract drilling and excavation as well as installation labor, 4) routine maintenance during field trials, 5) nonroutine maintenance including equipment repair and extra trips for repairs, and 6) routine data reduction, interpretation and evaluation. The Phase I costs associated with designing the system included some costs associated with evaluating many types of equipment as well as final selection of the site. These costs would not normally be included in system design and have not been included in this analysis. Each of the five are discussed below. The system design task costs were approximately \$20,000, which were predominately engineering labor in choosing the instruments, electronic equipment and preparing drawings and instructions for installations. It should be noted that, although the work on this project was spread over two years, most of the money was spent in 1979 and, thus, all dollars specified in this section represent 1979 dollars.

The installation hardware costs, which represent the instruments, cable and ADAS, cost a total of approximately \$85,300. The cost to install this equipment, including subcontractor costs and subsistence costs for the engineer during installation, was approximately \$73,000. The routine monitoring costs which included 5 man-trips back to the site plus computer data reduction programming, were approximately \$42,400. Some of the time and money expended in the field trials were for nonroutine maintenance but this time is difficult to separate from routine monitoring.

Finally, evaluation and interpretation costs were approximately \$10,700, which are mostly labor charges. Thus, the total cost of this instrumentation system has been approximately \$228,000.

The cost of any instrumentation system is highly dependent on the number, location and type of instruments used. Also, much of the cost for this particular system was associated with system development time which would be reduced in future multiple systems. In addition, the Montcoal, West Virginia, site was a long distance from our offices, and much of the routine monitoring costs were air travel time and expenses.

6.5 Cost Comparisons for Various Systems

While reviewing various ADAS used recently in the geotechnical field as part of Phase I, we attempted to obtain cost information. Many of the systems formed part of a larger program and technical personnel involved did not know the actual cost.

The Land Movement Monitoring System near Grand Coulee Dam cost approximately $240,000, including hardware, installation and routine monitoring, according to Bailey (1980). This system included 123 sensors, all of the servo-accelerometer type and was discussed in an earlier section of this report. The Grand Coulee monitoring system, containing a larger number of identical sensors, probably is most similar to our system and its costs are within the same range as ours. Bailey (1980) notes that a second system which consists of 21 sensors is being installed nearby at a cost of approximately $100,000. However, it should be recognized that costs for this type of system cannot be easily projected to a general system due to differing requirements on each project.

Since detailed cost data for a similar remote monitoring system were unavailable and may not be suitable for comparison basis, we decided to compare the costs of the present system to a postulated manual readout system at the same site. There are two advantages to this approach. First, variations due to number of sensors and types of instruments are not introduced into the analysis. Secondly, one of the major arguments for ADAS or remote monitoring systems is that monitoring labor and data processing costs can be reduced by utilizing the automated systems rather than manual readings. For this analysis, we have assumed that the same number and type of instruments are installed at the site but have eliminated the costs associated with cables, and automatic readout equipment and have substituted the cost of manual readout equipment. Table 6.1 lists the costs we have utilized in our analysis. By selecting some typical monitoring frequencies we have prepared estimated cost curves for both automatic and manual data collection. An eight-year life of project has been assumed since this is a reasonable project life and is also a generally accepted life of electronic equipment. A longer project life would favour the automatic monitoring system while a shorter life would favor the manual system. No attempt has been made to consider cost of money for the capital expenditure of the automatic system nor inflation for the labor rates over the eight years. The assumptions used in estimating costs are so approximate that such sophisticated economic techniques are not justified.

TABLE 6.1

Cost Analysis of Manual and Remote Monitoring Systems

Costs	Manual[1]	Automatic
System Design	$10,000	$20,000
Capital (includes equipment, instruments, cable, etc.)	$62,000	$85,000
Installation Labor	$60,000	$73,000
Maintenance Costs	$ 2,000/year	$20,000/year
Monitoring Labor	$ 116/set[2]	$ 15/set[2]
Data Processing Labor	$ 58/set[2]	$ 5,000/1st year Zero after that
Data Interpretation	$10,000/year	$10,000/year

1 Manual costs calculated from automated system costs.
2 Based on labor rate of $29/hour.

Note: All costs based on 37-sensor system.

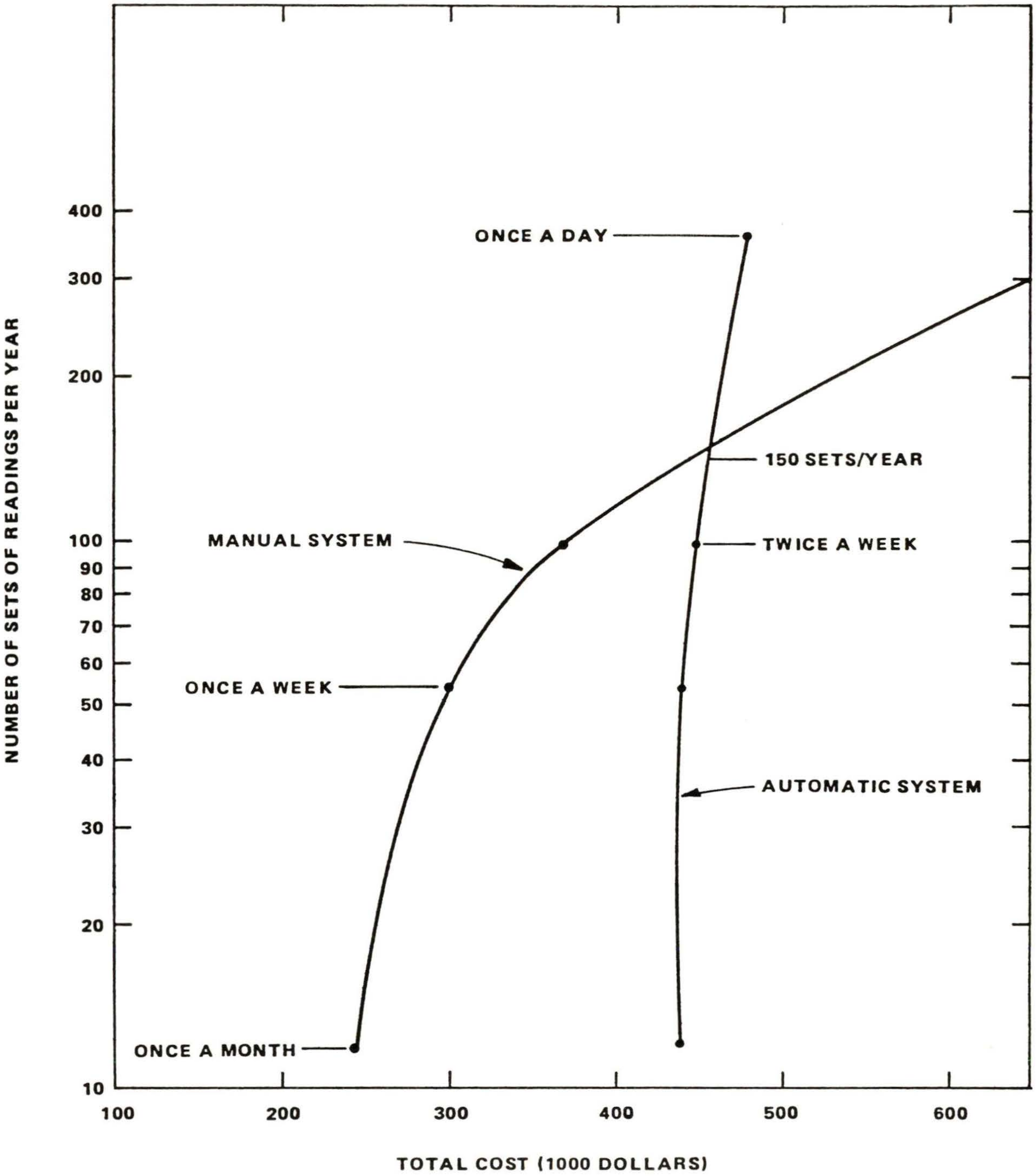
The frequency of readings which were chosen for the analysis included : 1 per month (12 per year), 1 per week (52 per year), 100 per year and 1 per day (365 per year). These frequencies are those which might be expected at a coal waste impoundment. Figure 6.1 shows the two curves developed from the data. The two systems have equal total costs at a reading frequency of approximately 150 sets per year which corresponds to about three readings per week. Thus, this analysis suggests that for an instrumentation system of the size used in this project, automatic data acquisition should be considered when the frequency of readings required exceeds approximately three times a week. Of course the number of sensors in a system will have a great effect on the cost effectiveness of an automatic system. Since the number of sensors was fixed in this project, the cost information does not lend itself to analysis of manual versus automatic costs as a function of number of sensors. In past projects we have observed that the frequency of readings is a much more powerful cost parameter than the number of sensors.

So far in the analysis, only manual on-site versus automatic readings have been considered with little concern for remote off-site monitoring. If data must be collected off-site using telemetry, the capital and installation costs of either an automatic or manually monitored off-site system will be similar. Thus, the lower operating costs of an automated system would then swing the economic analysis in favor of the automatic system.

6.6 Cost/Benefit Analysis

An economic cost/benefit analysis on this equipment is very difficult to perform with any realistic results. The costs for a particular system can be accurately estimated in economic terms after the project has been completed, but the economic benefits are a bit nebulous. Instrumentation for large earthen impoundment structures, including dams, is generally installed and monitored for safety purposes. Some of the obvious costs of having an impoundment failure are: loss of life downstream, property damage downstream, rebuilding of the impoundment and very bad public relations. Some that are less obvious, but still of importance to the mine include: shutdown of the preparation plant and mine due to lack of waste disposal facilities, the increased difficulties of obtaining permission to rebuild the impoundment and permit renewal for other nearby impoundments. Establishing how often instrumentation is responsible for helping in preventing an impoundment from failing and the cost of this benefit is impossible due to lack of data. In addition, assessing the number of instruments and the frequency of reading required to adequately monitor stability is very subjective and dependent on site-specific conditions. On most large civil engineering impoundment projects, the installation and monitoring of geotechnical instrumentation for public safety is standard practice and is not subject to cost/benefit analysis. The instrumentation scheme is chosen through a combination of a fixed schedule for a certain type of structure plus additional instruments based on the recommendations of a board of consultants.

Some economic benefits can occur by using instrumentation through the use of the information to produce less conservative designs for future projects, although the actual dollar benefit of this would be small for a coal waste impoundment. In addition, this type of instrumentation is usually short-term and carried out mostly through the construction phase, whereas long-term monitoring is usually exclusively for safety.



NOTE: COSTS BASED ON 37 SENSOR SYSTEM WITH A TOTAL LIFE OF 8 YEARS

FIG. 6.1 Monitoring Costs as a Function of Number of Readings

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

As part of the first phase of the project, we reviewed the literature, our past projects, and contacted other firms and individuals for examples of remote monitoring which would apply to coal waste impoundments. No remotely monitored coal waste impoundments were located in the search. We utilized information derived from automated instrumentation projects associated with large earth and concrete water retaining structures, and remote monitoring projects associated with meteorologic and hydrological parameters. It should be noted that both these categories are relatively new fields and extensive effort has been expended in the development and deployment of the various sytems. The instrumentation of a large earth dam probably most closely approximates a coal waste impoundment since the parameters being measured are similar.

Before the Buffalo Creek disaster in 1972, coal waste impoundments in the U.S. were not even engineered, but rather were simply created by dumping waste in a convenient valley. A similar situation existed in Britain prior to the Aberfan disaster in 1966. Now waste tips and impoundments are required to be designed and carefully monitored during construction. Most of the techniques and engineering analyses used on waste impoundments today were developed over many years by engineers in earth dam design and experimentation. In this project we have attempted to utilize as much of earth dam instrumentation technology as possible.

After reviewing literature on the size, design and construction of coal waste impoundments, we made detailed site visits to several candidate impoundments. The Montcoal, West Virginia site was found to both be typical of active coal waste impoundments within Eastern United States and characteristic of a particular type of construction sequence, the upstream method. Based on engineering design procedures, it was logical to assume that construction technique would influence the magnitude of the geotechnical parameters which would be measured. Thus, the information obtained at Montcoal could be utilized on future projects by engineers. In addition, the Montcoal site was relatively near an electrical power line and a telephone line.

Installation of the various sensors and drilling boreholes proceeded smoothly at a technical level, but some difficulties were encountered associated with using non-UMWA drillers. Procurement of some of the electronic monitoring equipment severely delayed completion of installation and system start-up. During monitoring, three types of problems were encountered which prevented continuous, uninterrupted monitoring for the planned 6-month period. First, electrical power and telephone service to the instrumentation trailer were repeatedly disrupted and, finally, mains electrical power was permanently lost when the nearby mine which supplied the power was closed.

The second class of problems was associated with breakdown in the sensors and electronic monitoring equipment. Part of this problem was associated with rushing the system into the field and not performing extended bench tests in the laboratory.

The third class of problems was caused by continuing construction and maintenance of the impoundment. In one case, the pond level sensor was destroyed during embankment extension, and in a second case buried cables were destroyed by a road grader. This type of problem seems to plague most all types of instrumentation on large earth-moving projects. The only solution appears to be a full-time employee at the construction site who is responsible for preventing damage and rapidly repairing damage which does occur.

Accurate and complete maintenance records of other geotechnical instrumentation monitoring are not generally available to compare with results of the Montcoal system. Based on some of our personal experiences, the performance of the Montcoal system is typical of large earth dams.

The relevant parameters and, consequently, the sensors used on the present system are typical of large earth dams. Appropriate models and number of sensors are dependent on individual site characteristics such as size of embankment, type of construction materials, foundation conditions, etc. Based on the site-specific characteristics at the Lower Big Branch impoundment and the results of the monitoring program, it is our opinion that the most important sensors for this site are piezometers, inclinometers and pond level sensor. All of these sensors provide important information for evaluating stability. The other sensors did, however, provide information which would be useful in evaluating the engineering properties of the coal waste. Unfortunately, the pond level sensor was destroyed before any data could be collected. Most of the problems with other sensors were the result of total failure of the instrument, with the exception of tiltmeter TM-3 and the in-place inclinometers. Thus, an instrument either provided a value for the parameter which was accurate enough for engineering purposes, or failed to respond entirely.

A large proportion of the difficulties with the signal conditioning equipment can be attributed to modifications of the equipment for this project. Any equipment specially modified is more likely to experience difficulties and require redesign.

It should be noted that automatic unattended monitoring systems have been used successfully in other fields. In particular, the hydrologic and meterologic sciences have utilized a large number of small data loggers for several years. In mining, a few automatic systems have been developed for particular situations or projects. Two examples are provided in McVey and Meyer (1973) and McVey and Serbousek (1976). These two projects are not directly applicable to coal waste impoundment monitoring but do provide ideas for other mining-related measurement situations performed under hostile environmental conditions.

Installing and maintaining an automated geotechnical instrumentation system can be very complicated and require specialized skills not generally found in the geotechnical engineering or mining fields. Thus, a mining company would not necessarily have on its staff personnel qualified to set-up and maintain such a system and either outside consultants or a special governmental group would need to be assigned to operate monitoring systems similar to the one utilized in this project. One possible alternative is to utilize small data loggers, such as the Climatronics or Mars, which are environmentally enclosed and designed for low maintenance and relatively low cost, approximately $5,000. These units are designed for meteorological measurements and some signal conditioning modification would be necessary for geotechnical sensors. However, these units might be acceptable at a coal waste impoundment, particularly if only one type of sensor is utilized. These units can either record data on magnetic tape or communicate over standard electronic interfaces and telephone links.

Finally, it should be noted that automatic remote monitoring is not necessarily the solution to "coal waste" impoundment monitoring for all impoundments. For small numbers of sensors, infrequent reading, short-term monitoring and large geographic areas, manual on-site readings with portable instruments could well be more economical than an automated system due to the generally lower capital costs of the manual system. The decision to either manually or automatically monitor must be made after considering the specific circumstances of each site.

7.2 Recommendations

7.2.1 Existing On-Site Instrumentation System

After carefully reviewing the results from the field trials and the data which were collected, we offer the following recommendations for improving the existing instrumentation system at Montcoal.

- Provide a more reliable source of electrical power for the instruments.
- Replace the vibrating wire piezometers with resistance-type piezometers.
- Improve the electronic signal conditioning equipment.
- Redesign and replace the pond level sensor.

Besides the improvements in the system just mentioned, we recommend that monitoring be continued at this site to obtain additional data on the embankment performance. Data should be collected until the filling of the impoundment with fine waste is complete. The information so collected could be utilized in analysis of the stability of this structure in particular, and coal waste impoundments in general.

7.2.2 Recommendations for Instrumenting Future Sites

Assuming that geotechnical parameters are to be remotely monitored at additional sites, we make the following recommendations for these systems:

- Certain equipment such as the data logger and signal conditioning be standardized and designed to handle about 15 individual sensors.
- Initially, the system should be flexible enough to accept a number of different sensor types.
- Satellite data transmission be investigated if more than 10 sites are to be instrumented.
- Alternate power sources, particularly solar, be investigated along with less power-consuming electronic equipment.
- Obtain more involvement by the local mine in maintaining the system or alternately utilize local repair service.

- Review and attempt to utilize proven meteorologic data acquisition equipment for lower cost systems.

7.2.3 General Improvements in Geotechnical Instrumentation

During this study we observed several areas in geotechnical instrumentation which could be improved upon. These areas are not directly related to remote monitoring of coal waste impoundments, but are more generally related to all fields of geotechnical instrumentation. Those areas which are most likely to provide better instrumentation include:

- Better quality control in instrumentation manufacture. Some models require more testing before shipment to eliminate design or construction errors.

- Better electrical and mechanical equipment specifications.

- Electronic equipment better designed for field conditions, including a wider environmental operation range.

- Increased development in seismic and geophysical instruments for inclusion in ADAS.

7.2.4 Further Areas of Study

In any study of this size, complexity and importance, there are invariably areas in which little information, techniques or equipment exist. In many cases, these areas need to be pursued in order to realize the study goals or to attain some future goal. The general purpose of this project was to develop a rapid and practical monitoring system to assess the performance of coal waste impoundments. Towards the general goal of improving the collection of engineering data from impoundments, we suggest the following areas of study for future projects.

- Assess need for and develop additional in-situ property measurement tools for embankment construction material. We located few in-situ property measuring tools in soil instrumentation, almost none which could be easily interfaced with an ADAS.

- Develop a standard remote monitoring system applicable for most coal waste impoundments as well as other mine waste impoundment structures, such as uranium tailings and metal mine impoundments.

- Combine results of subsurface investigations with data from satellite reconnaissance of surface movements.

APPENDIX A

Table of Contents

References

BAILEY, D.J.
Land Movement Monitoring System. Bulletin of the Association of Engineering Geologists, Vol. XVII, No. 4, 1980, pp. 213-221.

BELALA, T.
Personal Communication, 1978, U.S. Corps of Engineers, Lower Mississippi Division, Vicksburg, Mississippi.

CARTER, B.
Personal Communication, 1979, U.S. Bureau of Reclamation, Grand Coulee Dam.

CLARK, S.
Personal Communication, 1978, U.S. Corps of Engineers, Libby Dam.

COOK, E. W. and PRICE, G.
Horizontal Inclinometer for the Measurement of Vertical Displacement in the Soil Around Experimental Foundations. Field Instrumentation in Geotechnical Engineering. Halstead Press, 1974, pp 112-125.

DEKKER, J. (1979)
Personal Communication, 1979, Ebasco Services.

HANNA, T. H.
Foundation Instrumentation. Trans Tech Publications. Clausthal, W. Germany, 1973, 372 pp.

HAWKES, I.
Measurement of Mine Roof Movement. Final Report for U.S. Bureau of Mines Contract No. H0366033, 1978, 137 pp.

LAROCQUE, G.
Pit Slope Manual, Chapter 8 - Monitoring, CANMET Report 77-151, 1977, 187 pp.

McVEY, J.R. and MEYER, T.O.
An Automatic Data Acquisition System for Underground Measurements. Report of Investigations 7734, U.S. Bureau of Mines, 1973, 10 pp.

McVEY, J.R. and SERBOUSEK, M.O.
How Computerized Instrumentation Monitors Coal Mine Roofs. Mining Engineering, Vol. 40, September, 1976, pp. 40-43.

NESS 78
Geostationary Operational Environmental Satellite/Data Collection System. NOAA Technical Report NESS 78, 1979, 72 pp.

ROBERTS, R.
Personal Communication, 1978.

SINCO
How to Wire a Mountain. The Indicator. Slope Indicator Co., June 1974, Volume 6, Number 1, pp 1-5.

VAUGHAN, P. R.
The Measurement of Pore Pressure with Piezometers. Field Instrumentation in Geotechnical Engineering. Halstead Press, 1974, pp 411-422.

WILSON, S. D.
Personal Communication, 1979, Consulting Engineer, Seattle.

Bibliography

CORDING, E. J., HENDRON, A. S., HANSMIRE, W. H., MAHAR, J. W., MACPHERSON, H. H., JONES, R. A. and O'ROURKE, T. D.
Methods for Geotechnical Observations and Instrumentation in Tunneling. Department of Civil Engineering. University of Illinois. National Science Foundations Research Grant GI-33644X, 1975, 566 pp.

FIELD INSTRUMENTATION IN GEOTECHNICAL ENGINEERING
Butterworths. London, 1974, 720 pp.

HANNA, T. H.
Foundation Instrumentation. Trans Tech Publications. Clausthal, W. Germany, 1973, 372 pp.

RECENT DEVELOPMENTS IN GEOTECHNICAL ENGINEERING FOR HYDRO PROJECTS: ENGINEERING GEOLOGY ASPECTS, ROCK MECHANICS STUDIES AND EMBANKMENT DAM INSTRUMENTATION
American Society of Civil Engineers, New York, 1981, 250 pp.

SCHUSTER, R. L. and KRIZEK, R. H.
Landslides Analysis and Control. Special Report 176. Transportation Research Board. Washington, D.C., 1978, 234 pp.

U.S. DEPARTMENT OF TRANSPORTATION, FEDERAL HIGHWAY ADMINISTRATION
Geotechnical Instrumentation, Training Course Manual, 1980.

CANMET
Monitoring. Chapter 8. Pit Slope Manual. Ottawa, Canada, 1977, 188 pp.

APPENDIX B

Table of Contents

Annotated List of Automatic Data Acquisition Systems

B.C. Hydro

High precision tiltmeters were installed in boreholes within a slide area. The output voltage, proportional to tilt, is converted to an analog (FM) radio frequency and transmitted at 10-minute intervals to an ancillary service building which is 3 miles distant. Voltage level is monitored and recorded at building by technicians. Both the tiltmeters and transmitters are powered by batteries.

CANMET, Jeffery Mine

Various sensors were attached to a single, multi-position borehole extensometer. These sensors included: linear potentiometer, rotary potentiometer, linear variable differential transformer, mechanical encoder, and optical encorder. The electrical output of the sensors were multiplexed together and then digitized. A VHF radio transmitter then sent data to a base station which, in turn, was coupled by telephone to a master station. Details are presented in Pit Slope Manual, Chapter 8.

Lawrence Livermore Laboratories, Nevada Test Site, Nuclear Waste Disposal

A shaft has been instrumented with various sensors which are monitored remotely and automatically from the surface using an HP-1000 minicomputer. Data transmission is digital, electrical through high frequency scanner boxes. System has capability for future expansion as underground space is excavated. Minicomputer is dedicated to data collection and analysis and is connected to uninterruptable power supply.

U.S. Bureau of Reclamation, Yakima Basin

Eighteen remote data stations are polled 3 times per day automatically by computer. A maximum of 5 sensors at any one station measure hydrological parameters and transmit the data using UHF radio transmitters and repeaters to a PDP-11 computer at a base station. At the base station data is manipulated and organized for storage. Data is retransmitted from the base station by telephone to a computer center at Denver.

U.S. Bureau of Reclamation, Grand Coulee Dam

A Land Movement Monitoring system is employed near Grand Coulee Dam to continuously monitor movement of a landslide. One hundred twenty-three in-place inclinometer sensors are monitored using an automatic data logger, Acurex Autodata 9. As each sensor is scanned the value is linearized, engineering units added and checked for exceeding predetermined alarm limits. If the limits are exceeded an alarm is sounded both in the instrument shed and remotely. Periodically, data is recorded on magnetic tape for detailed analysis.

U.S. Corps of Engineers, Lower Mississippi Division

Hydrologic parameters of the lower Mississippi River are monitored automatically every 1 hour by a series of 125 remote stations along the river. Up to 12 sensors are connected at each station and data is transmitted every 4 hours by radio with a satellite (GOES) link to a central receiving station at Vicksburg, Alabama. Each station uses a mass produced Convertible Data Collection Platform to gather and transmit data. This system has been in operation since at least 1976.

U.S. Corps of Engineers, St. Louis District, Locks & Dam No. 26 Replacement

The Corps of Engineers is in the process of replacing Locks & Dam No. 26 on the Mississippi River. When completed, the geotechnical instrumentation will be monitored with a remote, automatic system utilizing an HP-1000 minicomputer. The following sensors will be included on the automatic system: Vibrating wire piezometers, tiltmeters, seismometers, barometer, and possibly other additional sensors. The central collecting area will contain the minicomputer which will interrogate remote stations through a fiber optic transmission network. The minicomputer will be accessible from the outside through telephone lines. Exact numbers of sensors will not be known until the project final phase is designed.

U.S. Bureau of Mines, Lucky Friday Shaft Instrumentation

A deep (approx. 7500 feet) shaft is being instrumented during construction under contract to the Bureau of Mines to measure deformations and pressures. Instruments include borehole extensometers, liner extensometers, and pressure cells at various levels of the shaft. Scanners at each level monitor the sensors and transmit the data up to the shaft to a minicomputer on the surface located in a trailer. Automatic monitoring is performed by the computer which also linearizes and plots the data for rapid evaluation.

U.S. Geological Survey, Hydrologic Information Service Pilot Program

A number of data collection platforms are placed at selected sites to collect data from water stage sensors and transmit it to a central data collection center in Concord, Massachusetts. The GOES is used as a data link. The central data collection center operated by Environmental Research and Technology, collects, reduces and integrates data into an information structure through computer processing. Data is then distributed to the customer through an intelligent communication network.

U.S. Corps of Engineers, Libby Dam

In 1972 a semi-automatic system was developed to monitor an unstable rock hillside which is one bank of Lake Koocanusa in Montana. The lake is the impounded reservoir for Libby Dam. Multiple-position borehole extensometers (123) and vibrating wire piezometers were monitored remotely by a specially constructed data logger which recorded information on punched tape. From the site data was transmitted by teletype and telephone to the Corps' office in Portland for computer processing.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL ENVIRONMENTAL SATELLITE SERVICE
Washington, D.C. 20233

July 1, 1980 OA/S131:DM

Mr. David A. Roberts
Engineer
Shannon and Wilson, Incorporated
1105 North 38th Street
Seattle, Washington 98103

Dear Mr. Roberts:

This is in reply to your letter of June 4, 1980 in which you asked about communication authorities that grant permission to transmit on assigned frequencies and a listing of various GOES Data Collection System (DCS) users and their use of the system. In addition, you requested that the National Environmental Satellite Service (NESS) evaluate a project from one of your clients as to its suitability for use of the GOES DCS. I will answer each of these questions in the order presented in your letter.

The U. S. National Agencies that have authority to grant permission to transmit on assigned GOES DCS channels are: (1) Interdepartmental Radio Advisory Committee (IRAC) for all Federal Agencies using the GOES DCS and (2) the Federal Communications Commission (FCC) for all other U. S. users of the GOES DCS. Each U. S. Federal Agency has a representative in their organization that is a member of the IRAC and their requests should be forwarded to that representative to obtain permission to transmit on the assigned frequency. All other users should forward their requests to the FCC. There are several FCC field offices located in various parts of the country that can be contacted for assistance in preparing the necessary paperwork.

I am enclosing a partial list of GOES DCS users that indicates typical uses of the system. NESS is publishing during the next few months a more comprehensive list of GOES DCS users with a brief explanation of the sensors employed and data relayed via the DCS. If you would desire a copy of this publication, please let me know.

NESS has evaluated the project included in your letter and finds that your client would qualify to use the GOES DCS. If your client decides to use the DCS, the formal application with the completed questionnaire should be sent to me for processing.

If you have any further questions, feel free to contact me.

Sincerely yours,

Douglas H. MacCallum
Chief, Data Collection and
Direct Broadcast Branch

Enclosure

10TH ANNIVERSARY 1970-1980
National Oceanic and Atmospheric Administration
A young agency with a historic
tradition of service to the Nation

List of Manufacturers of Equipment Referenced in Report

Acurex Autodata, 485 Clyde Ave., Mountain View, California 94042, (415)964-3200

Climatronics Inc., 140 Wilbur Place, Bohemia, New York 11716, (516)567-7300

Fredericks Co., Glass Components Division, Huntington Valley, Pennsylvania 19006, (215)947-2500

Hydrophilic Industries, Inc., 5815 North Meridian, Puyallup, Washington 98371, (206)927-4321

Irad Gage Inc., Etna Road, Lebanon, New Hampshire 03766, (603)448-4445

La Barge, Inc., Electronics Division, P.O. Box 36, Tulsa, Oklahoma 74101, (918)836-7611

Leupold & Stevens, Inc., P.O. Box 688, Beaverton, Oregon 97005, (503)646-9171

Mars Data Systems, P.O. Box 50335, Palo Alto, California 94303, (415)494-3975

Prentice Corporation, 795 San Antonio Road, Palo Alto, California 94303, (415)494-7225

Setra Systems, Inc., One Strathmore Road, Natick, Massachusetts 01760, (617)655-4645

Slope Indicator Company, 3668 Albion Place North, Seattle, Washington 98103, (206)633-3073

Solinst, Canada Ltd., 2495A Industrial Street, Burlington, Ontario, Canada L7P 1A6, (416)335-5611

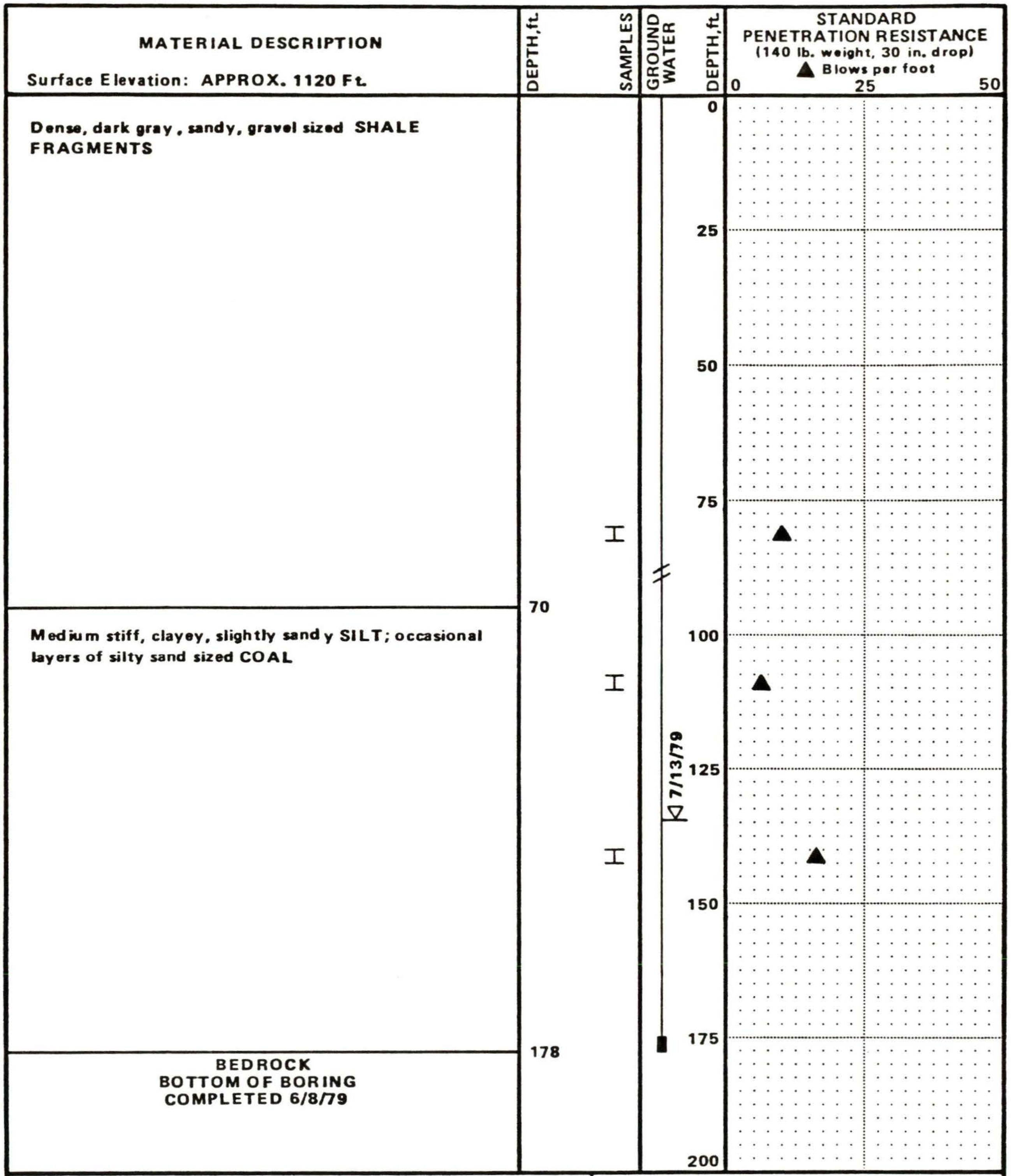
Terrametrics, 16027 W. 5th Ave., Golden, Colorado 80401, (303)279-7813

Terra Technology Incorporated, 3860 148th Ave. N.E., Redmond, Washington 98052, (206)883-7300

Topaz Electronics Division, 9192 Topaz Way, San Diego, California 92123, (714)279-0111

APPENDIX C

DETAILED LOGS OF INSTRUMENTATION BORINGS



MATERIAL DESCRIPTION

Surface Elevation: **APPROX. 1120 Ft.**

Dense, dark gray, sandy, gravel sized **SHALE FRAGMENTS**

Medium stiff, clayey, slightly sandy **SILT**; occasional layers of silty sand sized **COAL**

BEDROCK
BOTTOM OF BORING
COMPLETED 6/8/79

LEGEND

I 2" O.D. split spoon sample
Ⅲ NX diamond core sample

Impervious seal
Water level
Piezometer tip

NOTE: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

U.S.B.M. REMOTE MONITORING
LOWER BIG BRANCH
MONTCOAL, WEST VIRGINIA

LOG OF BORING B-1

AUGUST 1981 W-3466-08

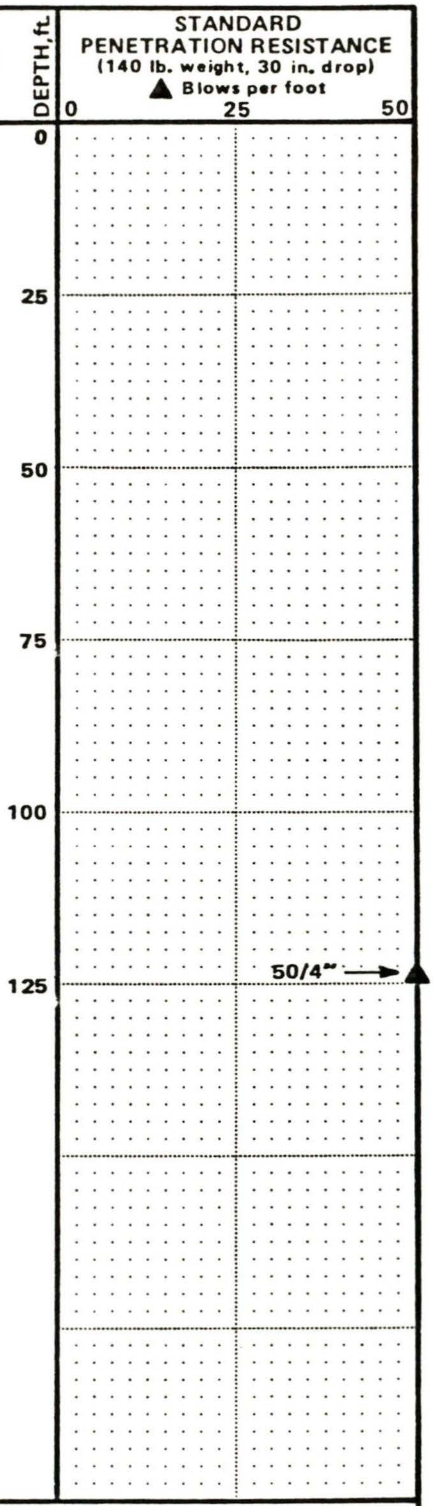
SHANNON & WILSON, INC.
Geotechnical Consultants

FIG. C-1

MATERIAL DESCRIPTION

Surface Elevation: APPROX. 1120 Ft.

MATERIAL DESCRIPTION	DEPTH, ft.	SAMPLES	GROUND WATER
Dense, dark gray, sandy, gravel sized SHALE FRAGMENTS			INCLINOMETER CASING INSTALLED ▽ 6/13/79
Medium stiff, black, slightly sandy, clayey, coal laden SILT, scattered coal fragments	75		
Medium, tan, SANDSTONE; iron oxide stains	124	Ⅲ	
BOTTOM OF BORING COMPLETED 6/13/79	129		


STANDARD PENETRATION RESISTANCE
(140 lb. weight, 30 in. drop)
▲ Blows per foot

LEGEND

- Ⅰ 2" O.D. split spoon sample
- Ⅲ NX diamond core sample
- Impervious seal
- ▽ Water level
- ■ Piezometer tip

NOTE: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

U.S.B.M. REMOTE MONITORING
LOWER BIG BRANCH
MONTCOAL, WEST VIRGINIA

LOG OF BORING B–2

AUGUST 1981 W-3466-08

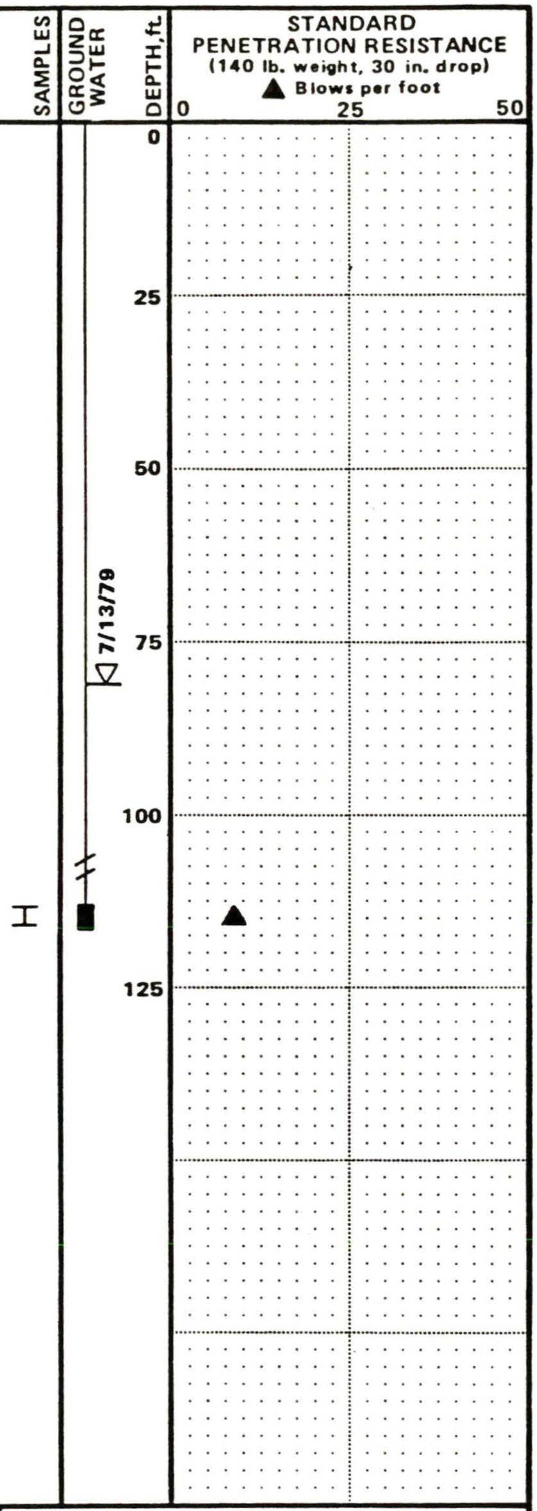
SHANNON & WILSON, INC.
Geotechnical Consultants

FIG. C-2

MATERIAL DESCRIPTION

Surface Elevation: APPROX. 1120 Ft.

MATERIAL DESCRIPTION	DEPTH, ft.
Dense, dark gray, sandy, gravel sized SHALE FRAGMENTS	50
Medium stiff, black, slightly sandy, clayey, SILT; occasional layers of sand sized COAL	117
BOTTOM OF BORING COMPLETED 6/18/79	



LEGEND

I 2" O.D. split spoon sample

III NX diamond core sample

╪ Impervious seal

▽ Water level

■ Piezometer tip

NOTE: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

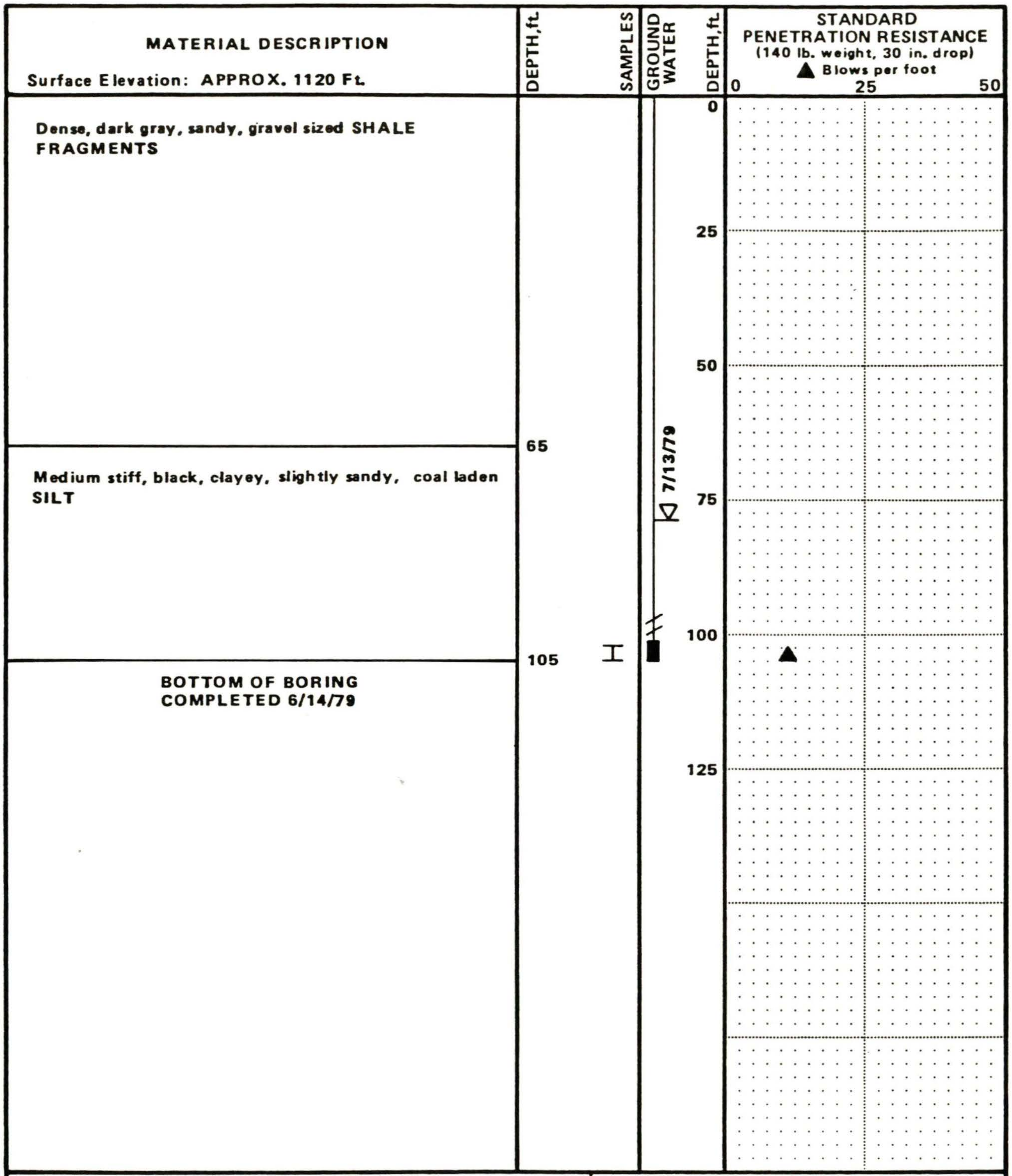
U.S.B.M. REMOTE MONITORING
LOWER BIG BRANCH
MONTCOAL, WEST VIRGINIA

LOG OF BORING B-3

AUGUST 1981 W-3466-08

SHANNON & WILSON, INC.
Geotechnical Consultants

FIG. C-3



MATERIAL DESCRIPTION

Surface Elevation: APPROX. 1120 Ft.

Depth, ft.	Material Description
	Dense, dark gray, sandy, gravel sized SHALE FRAGMENTS
65	Medium stiff, black, clayey, slightly sandy, coal laden SILT
105	BOTTOM OF BORING COMPLETED 6/14/79

LEGEND

I 2" O.D. split spoon sample

III NX diamond core sample

Impervious seal

▽ Water level

Piezometer tip

NOTE: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

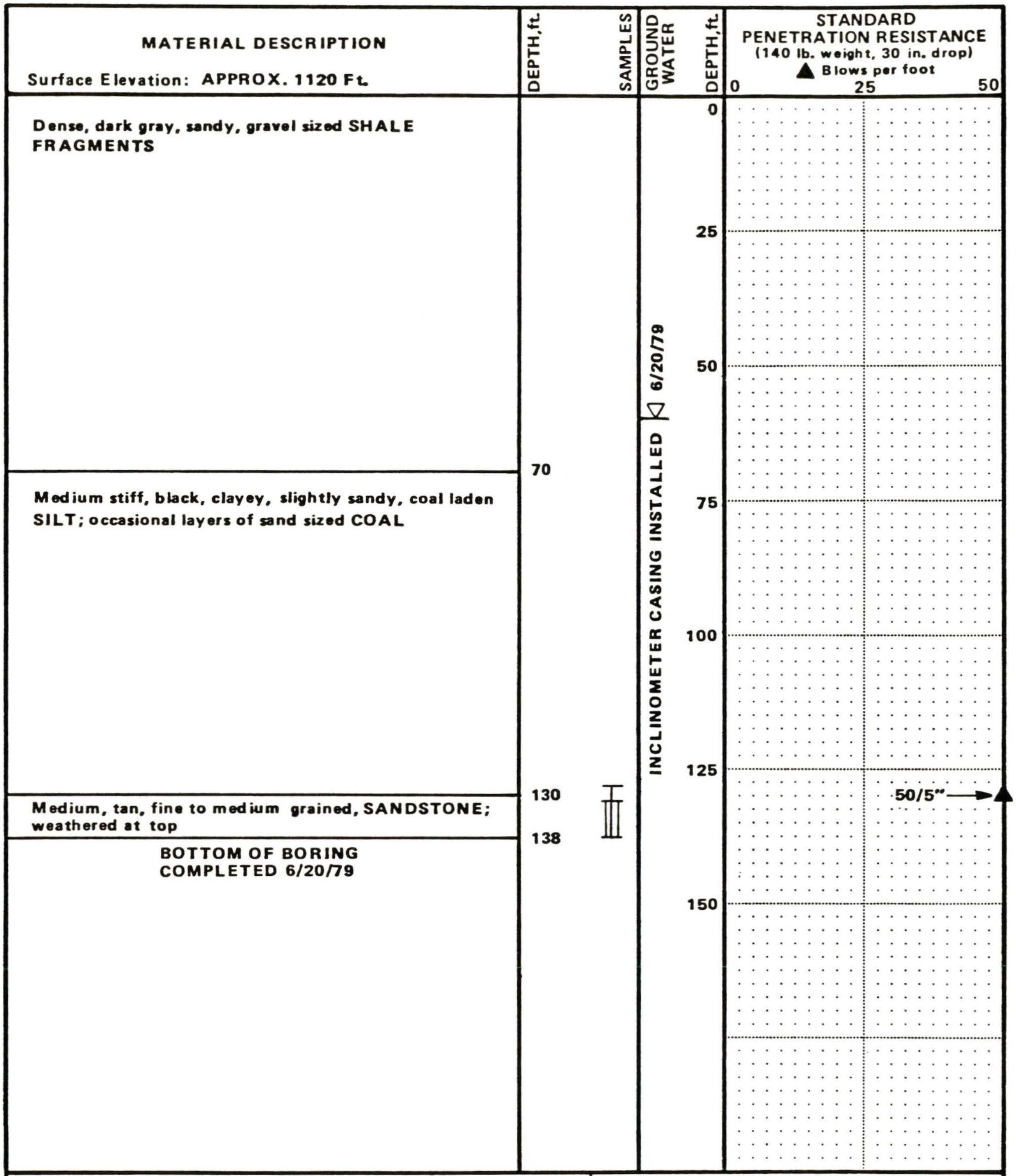
U.S.B.M. REMOTE MONITORING
LOWER BIG BRANCH
MONTCOAL, WEST VIRGINIA

LOG OF BORING B-4

AUGUST 1981 W-3466-08

SHANNON & WILSON, INC.
Geotechnical Consultants

FIG. C-4



LEGEND

Ⅰ 2" O.D. split spoon sample

Ⅲ NX diamond core sample

Impervious seal

▽ Water level

■ Piezometer tip

NOTE: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

U.S.B.M. REMOTE MONITORING
LOWER BIG BRANCH
MONTCOAL, WEST VIRGINIA

LOG OF BORING B–5

AUGUST 1981

W-3466-08

SHANNON & WILSON, INC.
Geotechnical Consultants

FIG. C-5

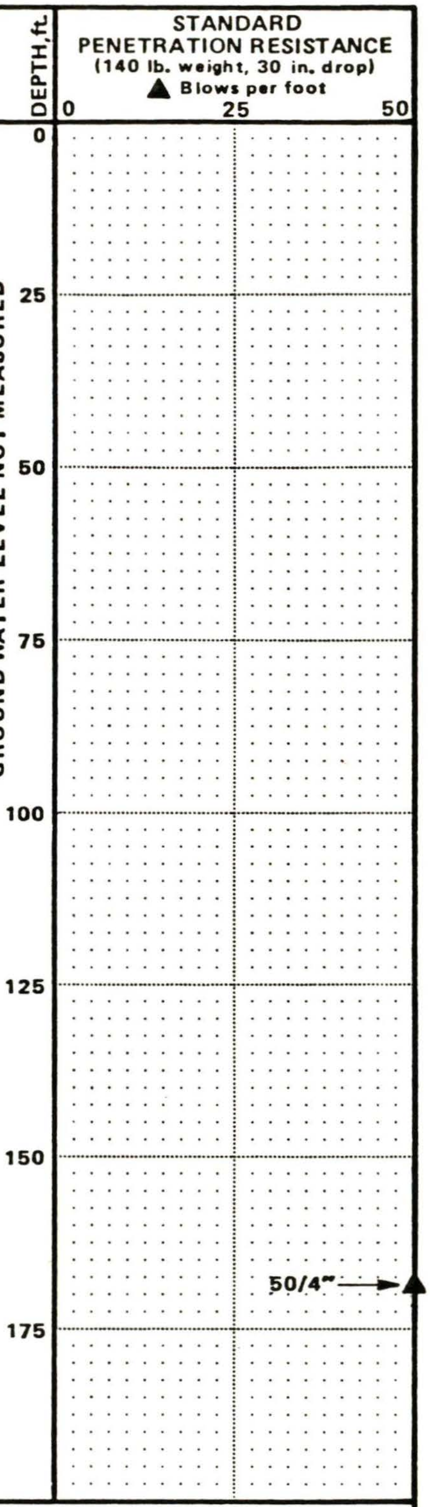
MATERIAL DESCRIPTION

Surface Elevation: APPROX. 1120 Ft.

MATERIAL DESCRIPTION	DEPTH, ft.	SAMPLES
Dense, dark gray, sandy, silty, slightly clayey, gravel sized SHALE FRAGMENTS	70	
Medium stiff, black, clayey, slightly sandy, coal laden SILT	169	
Medium tan, fine to medium grained SANDSTONE, upper part weathered	174	Ⅲ
Medium, black, fissile SHALE	175	

BOTTOM OF BORING
COMPLETED 6/25/79

GROUND WATER: MULTIPLE POSITION BOREHOLE EXTENSOMETER INSTALLED
GROUND WATER LEVEL NOT MEASURED



LEGEND

- Ⅰ 2" O.D. split spoon sample
- Ⅲ NX diamond core sample
- Impervious seal
- ▽ Water level
- Piezometer tip

NOTE: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

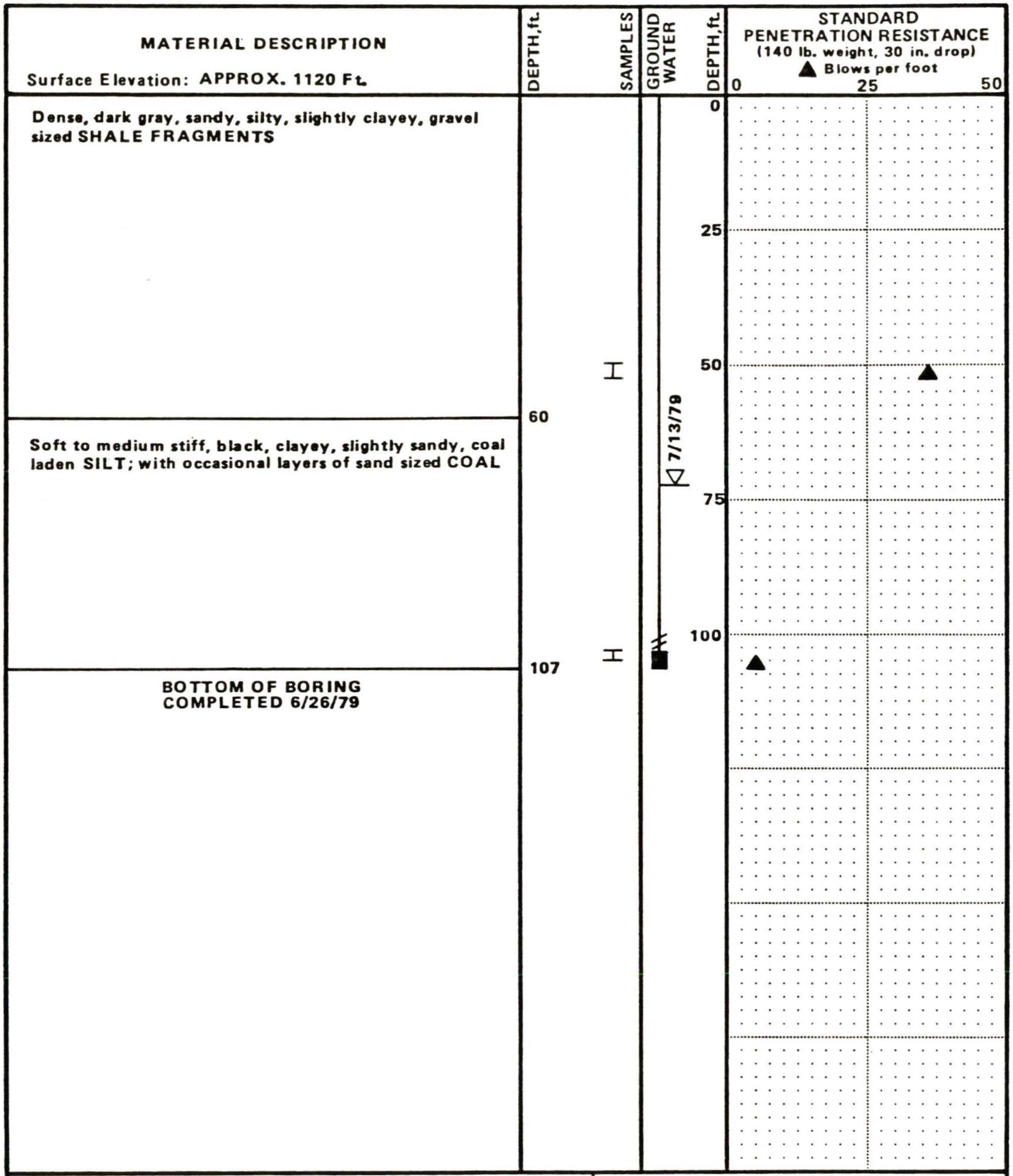
U.S.B.M. REMOTE MONITORING
LOWER BIG BRANCH
MONTCOAL, WEST VIRGINIA

LOG OF BORING B–6

AUGUST 1981 W-3466-08

SHANNON & WILSON, INC.
Geotechnical Consultants

FIG. C-6



Dense, dark gray, sandy, silty, slightly clayey, gravel sized SHALE FRAGMENTS

Soft to medium stiff, black, clayey, slightly sandy, coal laden SILT; with occasional layers of sand sized COAL

BOTTOM OF BORING
COMPLETED 6/26/79

LEGEND

I 2" O.D. split spoon sample

III NX diamond core sample

Impervious seal

▽ Water level

■ Piezometer tip

NOTE: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

U.S.B.M. REMOTE MONITORING
LOWER BIG BRANCH
MONTCOAL, WEST VIRGINIA

LOG OF BORING B-7

AUGUST 1981 W-3466-08

SHANNON & WILSON, INC.
Geotechnical Consultants

FIG. C-7

MATERIAL DESCRIPTION Surface Elevation: APPROX. 1120 Ft.	DEPTH, ft.	SAMPLES	GROUND WATER	DEPTH, ft.	STANDARD PENETRATION RESISTANCE (140 lb. weight, 30 in. drop) ▲ Blows per foot 0 25 50
Dense, dark gray, sandy, gravel sized SHALE FRAGMENTS			TILTMETER BASE INSTALLED	0 5 10	
BOTTOM OF BORING COMPLETED 6/26/79	8				

LEGEND

I 2" O.D. split spoon sample

III NX diamond core sample

Impervious seal

▽ Water level

Piezometer tip

NOTE: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

U.S.B.M. REMOTE MONITORING
LOWER BIG BRANCH
MONTCOAL, WEST VIRGINIA

LOG OF BORING B-8

AUGUST 1981 W-3466-08

SHANNON & WILSON, INC.
Geotechnical Consultants

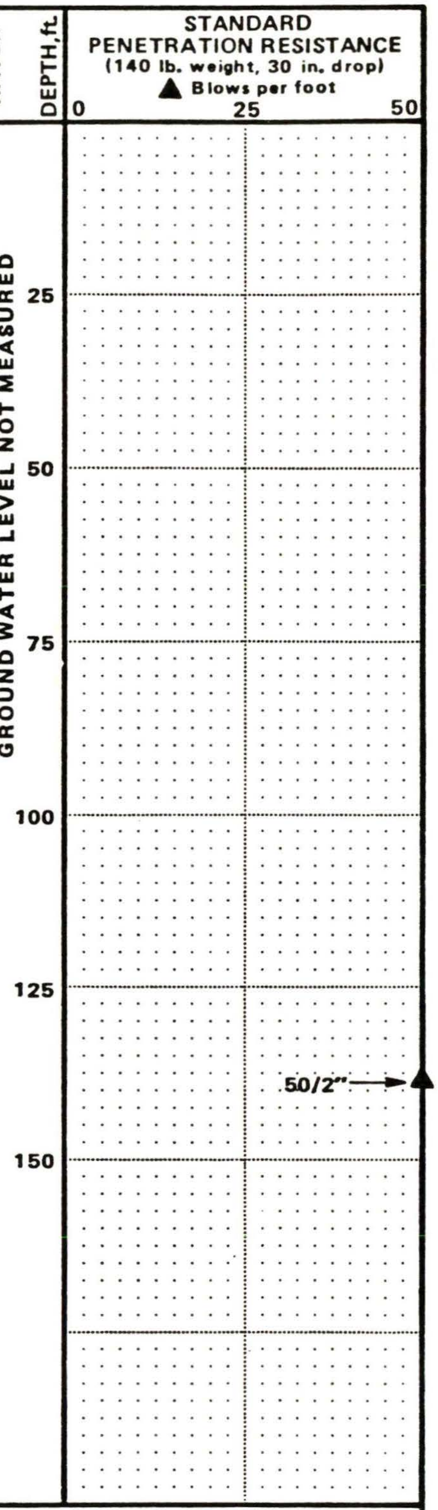
FIG. C-8

Surface Elevation: APPROX. 1120 Ft.

MATERIAL DESCRIPTION	DEPTH, ft.	SAMPLES
Dense, dark gray, sandy, silty, slightly clayey, gravel sized SHALE FRAGMENTS		
	65	
Medium dense, dark gray, gravel sized SHALE FRAGMENTS interbedded with layers of coal laden SILT		
	85	
Medium stiff, black, clayey, slightly sandy, coal laden SILT		
	137.5	Ⅰ
Medium, tan SANDSTONE, weathered		Ⅲ
	143	
BOTTOM OF BORING COMPLETED 6/27/79		

GROUND WATER

MULTIPLE POSITION BOREHOLE EXTENSOMETER INSTALLED
GROUND WATER LEVEL NOT MEASURED



LEGEND

Ⅰ 2" O.D. split spoon sample
Ⅲ NX diamond core sample
Impervious seal
▽ Water level
■ Piezometer tip

NOTE: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

U.S.B.M. REMOTE MONITORING
LOWER BIG BRANCH
MONTCOAL, WEST VIRGINIA

LOG OF BORING B-9

AUGUST 1981
W-3466-08

SHANNON & WILSON, INC.
Geotechnical Consultants

FIG. C-9

MATERIAL DESCRIPTION Surface Elevation: APPROX. 1120 Ft.	DEPTH, ft.	SAMPLES	GROUND WATER	DEPTH, ft.	STANDARD PENETRATION RESISTANCE (140 lb. weight, 30 in. drop) ▲ Blows per foot 0 25 50
Dense, dark gray, sandy, gravel sized SHALE FRAGMENTS			TILTMETER BASE INSTALLED	0 5 10	
BOTTOM OF BORING COMPLETED 6/28/79	9				

LEGEND

I 2" O.D. split spoon sample

III NX diamond core sample

Impervious seal

▽ Water level

▮ Piezometer tip

NOTE: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

U.S.B.M. REMOTE MONITORING
LOWER BIG BRANCH
MONTCOAL, WEST VIRGINIA

LOG OF BORING B-10

AUGUST 1981 W-3466-08

SHANNON & WILSON, INC.
Geotechnical Consultants

FIG. C-10

MATERIAL DESCRIPTION Surface Elevation: APPROX. 1120 Ft.	DEPTH, ft.	SAMPLES	GROUND WATER	DEPTH, ft.	STANDARD PENETRATION RESISTANCE (140 lb. weight, 30 in. drop) ▲ Blows per foot 0 25 50
Dense, dark gray, sandy, gravel size SHALE FRAGMENTS			TILTMETER BASE INSTALLED	0	
				5	
BOTTOM OF BORING **COMPLETED 6/28/79**	9				
				10	

LEGEND

I 2" O.D. split spoon sample

III NX diamond core sample

Impervious seal

▽ Water level

Piezometer tip

NOTE: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

U.S.B.M. REMOTE MONITORING
LOWER BIG BRANCH
MONTCOAL, WEST VIRGINIA

LOG OF BORING B-11

AUGUST 1981

W-3466-08

SHANNON & WILSON, INC.
Geotechnical Consultants

FIG. C-11

MATERIAL DESCRIPTION

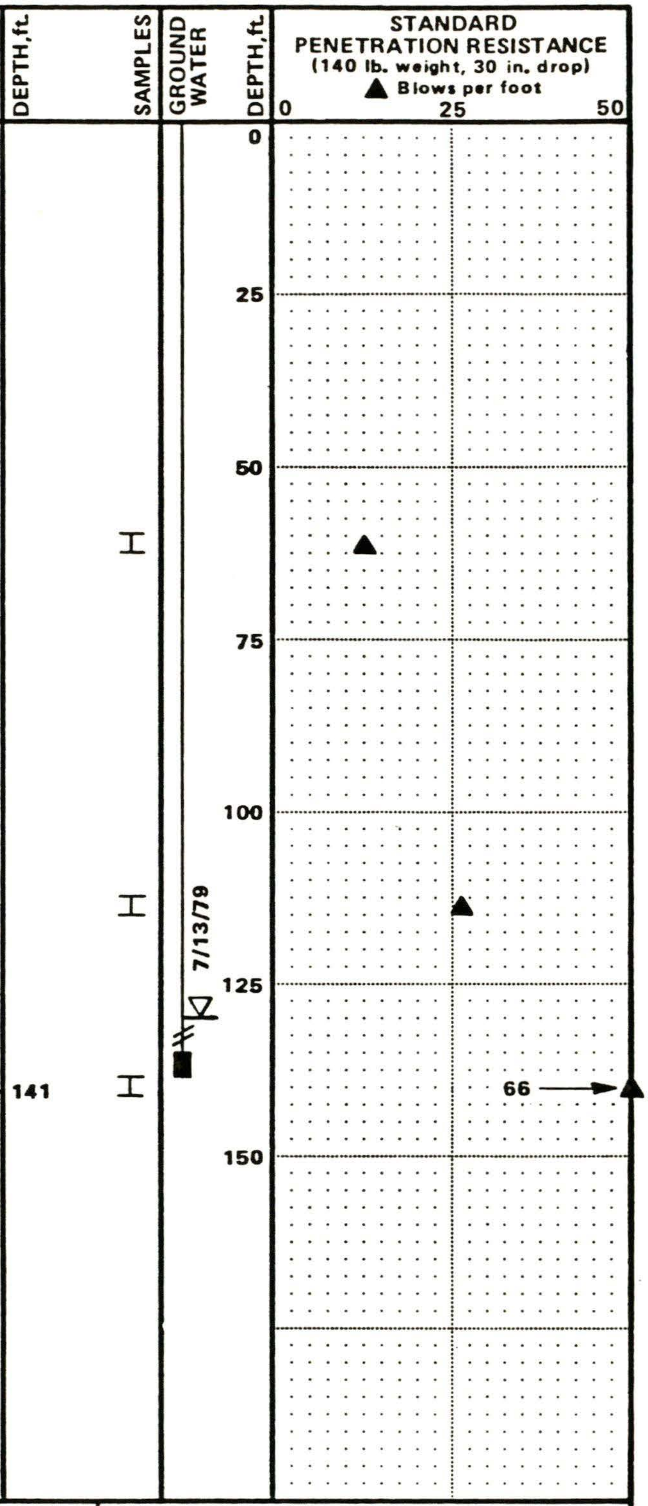
Surface Elevation: APPROX. 1082 Ft.

Medium dense to dense interbedded layers of dark gray, silty, slightly clayey, fine to coarse sand sized SHALE FRAGMENTS; silty, fine to coarse sand sized COAL FRAGMENTS; mixed COAL and SHALE FRAGMENTS

141

Tan, fine to medium grained SANDSTONE, weathered

BOTTOM OF BORING
COMPLETED 7/6/79



LEGEND

- I 2" O.D. split spoon sample
- Ⅲ NX diamond core sample
- Impervious seal
- ▽ Water level
- ■ Piezometer tip

NOTE: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

U.S.B.M. REMOTE MONITORING
LOWER BIG BRANCH
MONTCOAL, WEST VIRGINIA

LOG OF BORING B-12

AUGUST 1981

W-3466-08

SHANNON & WILSON, INC.
Geotechnical Consultants

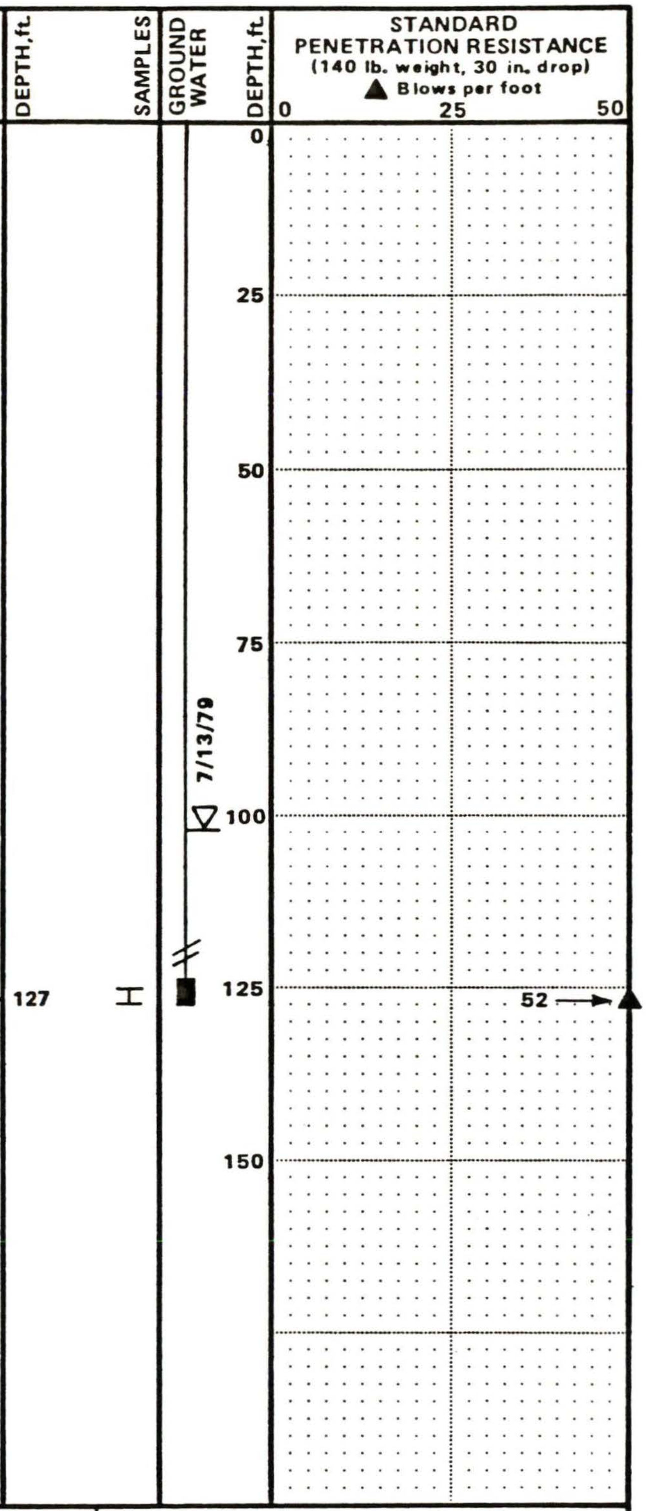
FIG. C-12

MATERIAL DESCRIPTION

Surface Elevation: APPROX. 1056 Ft.

Medium dense, dark gray, silty, coal laden, slightly clayey, fine to coarse SAND to fine gravel size SHALE FRAGMENTS, with occasional layers of coal fragments

Tan SANDSTONE
BOTTOM OF BORING
COMPLETED 7/10/79



LEGEND

I 2" O.D. split spoon sample
III NX diamond core sample

Impervious seal
Water level
Piezometer tip

NOTE: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

U.S.B.M. REMOTE MONITORING
LOWER BIG BRANCH
MONTCOAL, WEST VIRGINIA

LOG OF BORING B-13

AUGUST 1981 W-3466-08

SHANNON & WILSON, INC.
Geotechnical Consultants

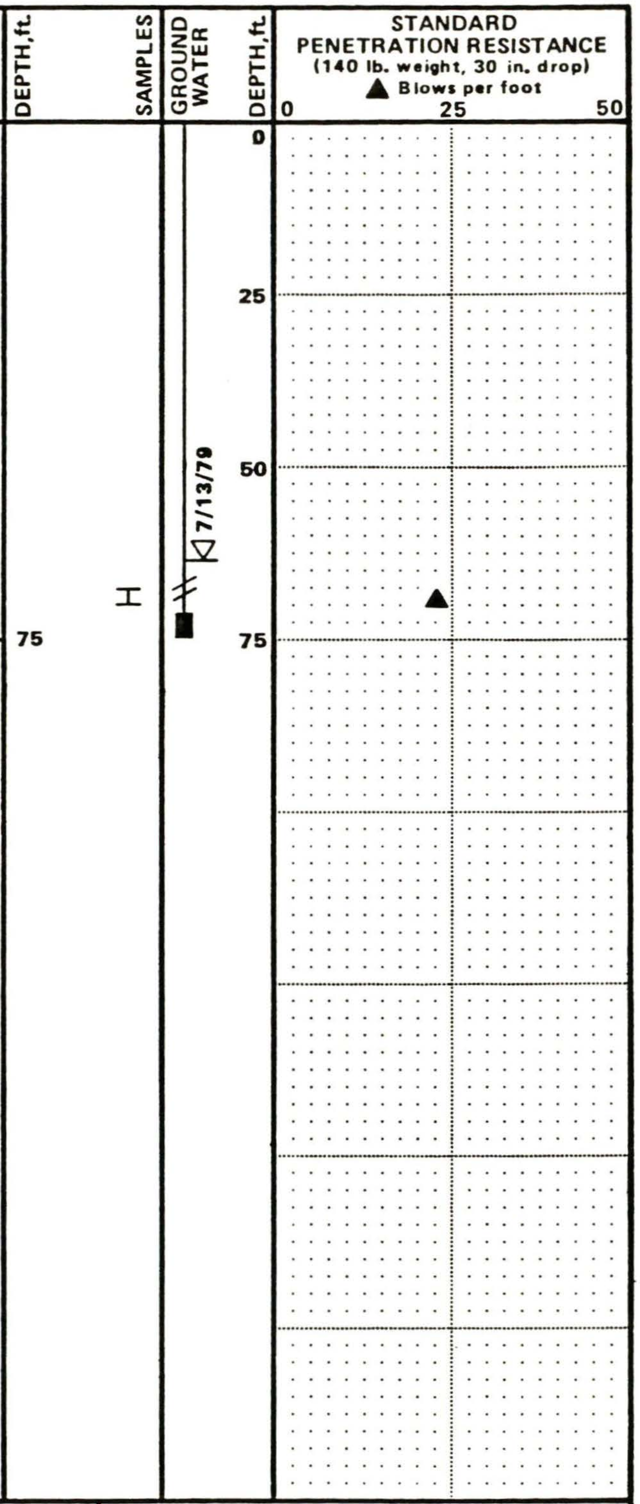
FIG. C-13

MATERIAL DESCRIPTION

Surface Elevation: APPROX. 993 Ft.

Medium dense, dark gray, silty, coal laden, slightly clayey, fine to coarse SAND to fine gravel sized SHALE FRAGMENTS, with scattered coal fragments

BEDROCK
BOTTOM OF BORING
COMPLETED 7/12/79



LEGEND

I 2" O.D. split spoon sample

III NX diamond core sample

Impervious seal

▽ Water level

Piezometer tip

NOTE: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

U.S.B.M. REMOTE MONITORING
LOWER BIG BRANCH
MONTCOAL, WEST VIRGINIA

LOG OF BORING B-14

AUGUST 1981

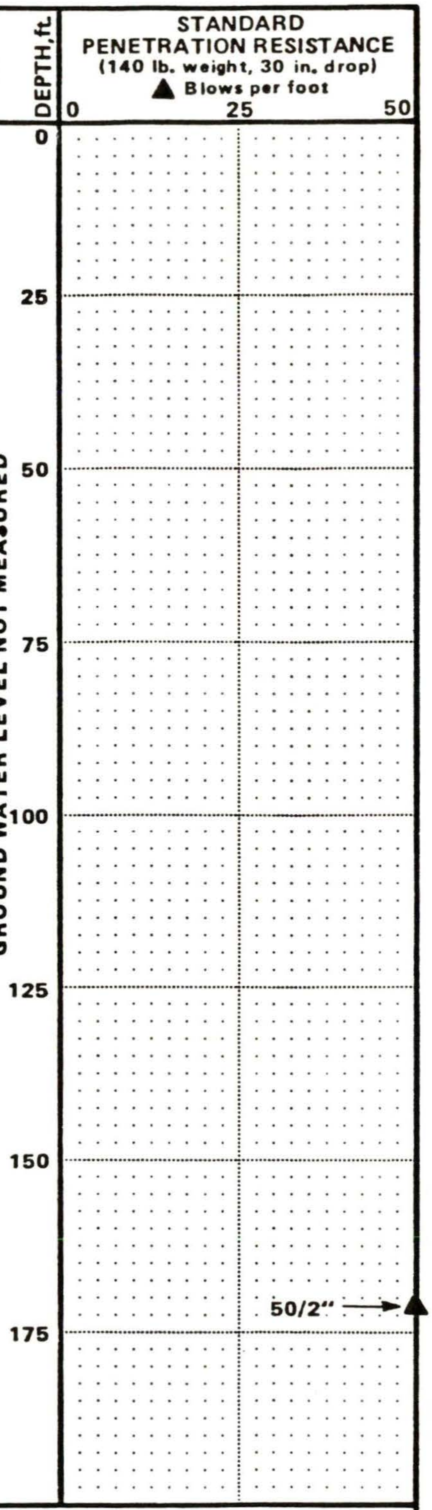
W-3466-08

SHANNON & WILSON, INC.
Geotechnical Consultants

FIG. C-14

MATERIAL DESCRIPTION Surface Elevation: APPROX. 1120 Ft.	DEPTH, ft.	SAMPLES
Medium dense, dark gray, silty, slightly clayey, sandy, fine to coarse gravel sized SHALE FRAGMENTS		
Medium dense, dark gray, slightly clayey, sandy, coal laden SILT, with occasional layers of sand sized COAL	70	
Medium, dark gray, sandy SHALE	172	III
BOTTOM OF BORING COMPLETED 7/13/79	177	

GROUND WATER: MULTIPLE POSITION BOREHOLE EXTENSOMETER INSTALLED
GROUND WATER LEVEL NOT MEASURED



LEGEND

I 2" O.D. split spoon sample
III NX diamond core sample

Impervious seal
Water level
Piezometer tip

NOTE: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

U.S.B.M. REMOTE MONITORING
LOWER BIG BRANCH
MONTCOAL, WEST VIRGINIA

LOG OF BORING B-15

AUGUST 1981
W-3466-08

SHANNON & WILSON, INC.
Geotechnical Consultants

FIG. C-15

APPENDIX D

INSTRUMENTATION SYSTEM WIRING CONNECTIONS

List of Tables

TABLE D-1

RESISTANCE ELECTRO-PIEZOMETER SIGNAL CONDITIONER CABLE CONNECTIONS

Junction Box Cable No.	Junction Box Terminal Panel	Wire No.	E/P Connector Pin No.	Function
CJS-2-33	TB21 -1	1	8-1	RP1 -1 PWR+
-34	-2	2	8-2	-2 PWR-
-35	-3	3	8-3	-3 SENSE-
-36	-4	4	8-4	-4 SIG-
-37	-5	5	8-5	-5 SIG+
-38	-6	6	8-6	-6 SENSE+
DL25H	-7	7	8-7	DL25 High RP1
DL25L	-8	8	8-8	DL25 Low RP1
CJS-2-39	-9	9	7-1	RP2 -1 PWR+
-40	-10	10	7-2	-2 PWR-
-41	TB22 -1	11	7-3	-3 SENSE-
-42	-2	12	7-4	-4 SIG-
-43	-3	13	7-5	-5 SIG+
-44	-4	14	7-6	-6 SENSE+
DL26H	-5	15	7-7	DL CHNL 26 High RP2
DL26L	-6	16	7-8	DL CHNL 26 Low RP2
PLS-1	-7	17	7-22	PLS -1 PWR+
PLS-2	-8	18	7-21	-2 PWR-
PLS-3	-9	19	7-20	-3 SENSE-
PLS-4	-10	20	7-19	-4 SIG-
PLS-5	TB23 -1	21	7-18	-5 SIG+
PLS-6	-2	22	7-17	-6 SENSE+
DL27H	-3	23	7-16	DL CHNL 27 High PLS
DL27L	-4	24	7-15	DL CHNL 28 Low PLS
	-5	25		Spare
	-6	26		Spare
	-7	27		Spare
	-8	28		Spare
	-9	29		Spare
	-10	30		Spare
TB9 -1	TB24 -1	31	+18	+Supply Voltage
-2	-2	32	+18	+Supply Voltage
-6	-3	33	GND	GND
-7	-4	34	GND	GND
TB10 -1	-5	35	-18	-Supply Voltage
-2	-6	36	-18	-Supply Voltage
Shield	-7	Shield		Shield

TABLE D-2

EXTENSOMETER SIGNAL CONDITIONER CABLE CONNECTIONS

Junction Box Cable No.	Terminal Box	Wire No.	Extensometer Connector Pin No.	Function	
CJS-1-29	TB31 -1	1	1-6	MPBX-1 #1	P
-30	-2	2	1-7		PS
-32	-3	3	1-4		G
-33	-4	4	1-5		GS
-34	-5	5	1-15	MPBX-1 #2	P
-35	-6	6	1-16		PS
-37	-7	7	1-17		G
-38	-8	8	1-18		GS
-39	-9	9	1-21	MPBX-1 #3	P
-40	-10	10	1-22		PS
-42	TB32 -1	11	1-19		G
-43	-2	12	1-20		GS
-44	-3	13	2-6	MPBX-1 #4	P
-45	-4	14	2-7		PS
-47	-5	15	2-4		G
-48	-6	16	2-5		GS
CJS-2-13	-7	17	2-15	MPBX-2 #1	P
-14	-8	18	2-16		PS
-16	-9	19	2-17		G
-17	-10	20	2-18		GS
-18	TB33 -1	21	2-21	MPBX-2 #2	P
-19	-2	22	2-22		PS
-21	-3	23	2-19		G
-22	-4	24	2-20		GS
-23	-5	25	3-6	MPBX-3 #1	P
-24	-6	26	3-7		PS
-26	-7	27	3-4		G
-27	-8	28	3-5		GS
-28	-9	29	3-15	MPBX-3 #2	P
-29	-10	30	3-16		PS
-31	TB34 -1	31	3-17		G
-32	-2	32	3-18		GS
Weir -1	-3	33	3-21	WEIR	P
-2	-4	34	3-22		PS
-4	-5	35	3-19		G
-5	-6	36	3-20		GS

TABLE D-3

DATA LOGGER CABLE CONNECTIONS

Junction Box Cable No.	Terminal Panel	Wire No.	Data Logger Connector	Chnl No.	Function
CJS-1 -1	TB7 -1	1	0	0	II -1 High
-2	-2	2	1	0	-2 Low
-3	-3	3	2	1	II -2 High
-4	-4	4	3	1	-2 Low
-5	-5	5	4	2	II -3 High
-6	-6	6	5	2	-3 Low
-7	-7	7	6	3	II -4 High
-8	-8	8	7	3	-4 Low
-9	-9	9	8	4	II -5 High
-10	-10	10	9	4	-5 Low
-11	TB8 -1	11	10	5	II -6 High
-12	-2	12	11	5	-6 Low
-13	-3	13	12	6	II -7 High
-14	-4	14	13	6	-7 Low
-15	-5	15	14	7	II -8 High
-16	-6	16	15	7	-8 Low
-23	-7	17	16	8	TM1-A High
-25	-8	18	17	8	-A Low
-24	-9	19	18	9	TM1-B Low
-25	-10	20	19	9	-B Low
-26	TB11 -1	21	20	10	TM2-A High
-28	-2	22	21	10	-A Low
-27	-3	23	22	11	TM2-B High
-28	-4	24	23	11	-B Low
CJS-2 -1	-5	25	24	12	TM3-A High
-3	-6	26	25	12	-A Low
—	-9	29	—	—	Spare -A High
—	-10	30	—	—	-A Low
—	TB12 -1	31	—	—	Spare -B High
—	-2	32	—	—	-B Low
CJS-1 -31	-3	33	28	14	MPBX-1 #1 SIG
-33	-4	34	29	14	G
-36	-5	35	30	15	MPBX-1 #2 SIG
-38	-6	36	31	15	G

TABLE D-3 (cont.)

DATA LOGGER CABLE CONNECTIONS

Junction Box Cable No.	Terminal Panel	Wire No.	Data Logger Connector	Chnl No.	Function .	
CJS-1 -41	TB12 -7	37	32	16	MPBX-1 #3	SIG
-43	-8	38	33	16		G
-46	-9	39	34	17	MPBX-1 #4	SIG
-48	-10	40	35	17		G
CJS-2 -15	TB19 -1	41	36	18	MPBX-2 #1	SIG
-17	-2	42	37	18		G
-20	-3	43	38	19	MPBX-2 #2	SIG
-22	-4	44	39	19		G
-25	-5	45	40	20	MPBX-3 #1	SIG
-27	-6	46	41	20		G
-30	-7	47	42	21	MPBX-3 #2	SIG
-32	-8	48	43	21		G
Wier -3	-9	49	44	22	Weir	SIG+
Weir -5	-10	50	45	22		SIG-
E/P-8 -7	TB20 -1	51	46	23	RP1	SIG+
-8 -8	-2	52	47	23		SIG-
-7 -7	-3	53	48	24	RP2	SIG+
-7 -8	-4	54	49	24		SIG-
-7 -16	-5	55	50	25	PLS	SIG+
-7 -15	-6	56	51	25		SIG-
—	—	–	52	26	Rain	High
—	—	–	53	26	Gage	Low
—	—	–	54	27	Bar	SIG
—	—	–	55	27		GS
—	—	–	56	28	TV1	High
—	—	–	57	28		Low
—	—	–	58	29	TV2	High
—	—	–	59	29		Low
—	—	–	60	30	TV3	High
—	—	–	61	30		Low
—	—	–	62	31	TC1	High
—	—	–	63	31		Low
—	—	–	64	32	TC2	High
—	—	–	65	32		Low

TABLE D-4

VIBRATING WIRE PIEZOMETER CABLE CONNECTIONS

Junction Box Cable No.	Junction Box Terminal Panel	MA-5SM Connector Pin No.	Function
VWP1-1	TB34 -8	0	High
VWP1-2	-9	0	Low
VWP1-Sh	-10	Chassis	Shield
VWP2-1	TB35 -1	1	High
VWP2-2	-2	1	Low
VWP2-Sh	-3	Chassis	Shield
VWP3-1	-4	2	High
VWP3-2	-5	2	Low
VWP3-Sh	-6	Chassis	Shield
VWP4-1	-7	3	High
VWP4-2	-8	3	Low
VWP4-Sh	-9	Chassis	Shield
VWP5-1	-10	4	High
VWP5-2	TB36 -1	4	Low
VWP5-SH	-2	Chassis	Shield
VWP6-1	-3	5	High
VWP6-2	-4	5	Low
VWP6-Sh	-5	Chassis	Shield
VWP7-1	-6	6	High
VWP7-2	-7	6	Low
VWP7-Sh	-8	Chassis	Shield

TABLE D-5

SENSOR CABLE COLOR CODE

Sensor Type	Wire Color	Pin No.*	Function
Multiple-position borehole Extensometers and Weir	Red	A	+ Power
	Black	B	Ground
	White	C	Ground Sense
	Blue	D	Signal
	Green	F	Power Sense
	Shield	G	Shield
In-place Inclinometers and Tiltmeters	Red	A	+ Power
	Black	B	- Power
	White	C	Power Ground
	Blue	D	A Signal
	Green	F	B Signal
	Yellow	E	Signal Ground
	Shield	G	Shield
Resistance Piezometers	Red	A	+ Power
	Black	B	- Power
	Green	F	+ Power Sense
	White	C	- Power Sense
	Blue	D	+ Signal
	Yellow	E	- Signal
	Shield	G	Shield
Vibrating Wire Piezometers	White	A	+ Signal
	Black	B	- Signal
	Shield	C	Shield

*Vibrating wire piezometers use 3-pin, MS3100 series environmental connectors. All other sensors utilize either terminal strips or 7-pin, MS3100 series connectors.