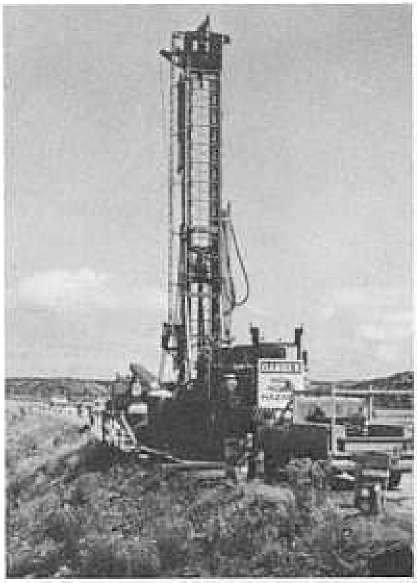
EMBANKMENT DAM INSTRUMENTATION MANUAL



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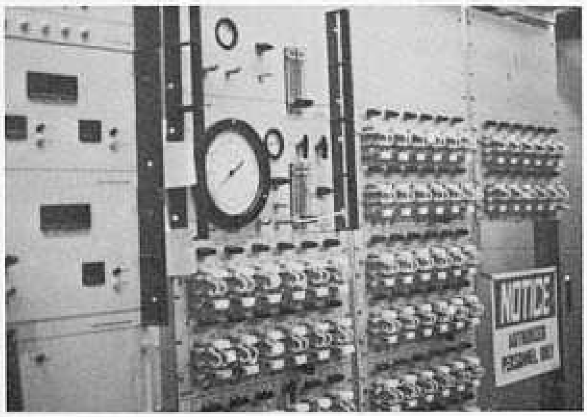

UNITED STATES DEPARTMENT OF THE INTERIOR
Bureau of Reclamation

7-2090 (4-81)
Bureau of Reclamation

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE Embankment Dam Instrumentation Manual		5. REPORT DATE January 1987
		6. PERFORMING ORGANIZATION CODE D-3352
7. AUTHOR(S) Charles L. Bartholomew, Bruce C. Murray, and Dan L. Goins		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Bureau of Reclamation Engineering and Research Center Denver, CO 80225		10. WORK UNIT NO.
		11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Same		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE DIBR

15. SUPPLEMENTARY NOTES

Microfiche and/or hard copy available at the E&R Center, Denver, Colorado

Editor:RDM(c)

16. ABSTRACT

Using instruments to gather information on the performance of an embankment dam is vital. The safety and proper functioning of a dam must be assessed continuously — during construction, during first filling of the reservoir, and during the service life of the dam.

Many types of instrumentation systems are used for embankment dams. Systems monitor water pressure, seepage, internal movement, surface movement, vibration, and other significant parameters.

The various instrumentation systems used by the Bureau of Reclamation are described in this manual, which is intended for designers, engineers, instrument readers, dam operators, and dam safety personnel. The history, purpose, and current usage of each type of system is discussed. Each system is described; its advantages and disadvantages are analyzed; and its installation, monitoring, and data handling procedures are outlined.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS--*instrumentation systems/ *data transmission/ *embankment dams/ pressure measuring instruments/ seepage/ vibration/ internal movement/ surface movement/ piezometers/ monitoring/ dam safety/ flumes/ sensors/ inclinometers/ tiltmeters/ data handling and review

b. IDENTIFIERS--

c. COSATI Field/Group 148 *COWRR:* 1402 *SRIM:*

18. DISTRIBUTION STATEMENT *Available from the National Technical Information Service, Operations Division, 5285 Port Royal Road, Springfield, Virginia 22161.* (Microfiche and/or hard copy available from NTIS)	19. SECURITY CLASS (THIS REPORT) *UNCLASSIFIED*	21. NO. OF PAGES 250
	20. SECURITY CLASS (THIS PAGE) *UNCLASSIFIED*	22. PRICE

EMBANKMENT DAM INSTRUMENTATION MANUAL

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January 1987

United States Department of the Interior ★ Bureau of Reclamation

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

ACKNOWLEDGMENTS

This manual was prepared under the general direction of Dewayne L. Misterek, Chief of the Structural Behavior Branch, Division of Dam Safety, Bureau of Reclamation, Denver, Colorado. The review comments of D. L. Misterek, Jay N. Stateler and L. Randall Welch, also of the Structural Behavior Branch, were greatly appreciated. J. N. Stateler was also invaluable in compiling and coordinating the review by other Bureau offices. Dr. Bartholomew, one of the principal authors, was employed by the Structural Behavior Branch during the summers of 1985 and 1986.

Significant contributions were also made by Andy Viksne, Head, Geophysics Section, in chapter VI; T. E. Backstrom, Head, Chemistry Section, in chapter VII, Lynn Carpenter and Jay N. Stateler of the Structural Behavior Branch, for portions of chapter VII, and Lawrence Gilchrist of the Structural Behavior Branch for Appendix B.

PREFACE

The *Embankment Dam Instrumentation Manual* has been prepared to provide the information needed for installation, operation, and analysis of instrumentation systems to designers, engineers, instrument readers, dam operators, and dam safety personnel. The manual is primarily intended for Bureau of Reclamation personnel. Nevertheless, other agencies or individuals, either in the United States or abroad, engaged in the design or construction of embankment dams or in the safety evaluation of dams may also find the information useful.

English-system units of measure are used throughout the manual because it is intended primarily for use in the United States. However, in recognition of the trend toward a more universal use of metric units, a metric equivalent conversion table has also been included.

References to commercial products or firms are intended only to present examples. Such references should not be construed as endorsements or recommendations by the Bureau of Reclamation.

Information used in preparing the manual has been drawn from many sources. An attempt to reference these sources has been made where appropriate. The references noted are listed in Chapter VIII, which contains a selected bibliography of publications related to embankment dam instrumentation.

It is currently planned to revise and update some portions of this manual after 2 to 3 years. Comments and suggestions by manual users are welcome.

CONVERSION FACTORS

English (inch-lb) units	S.I. (metric) units
1 inch	= 25.4 mm
1 foot	= 0.305 m
1 pound	= 0.454 kg
1 in^3	= 1.639×10^4 mm^3
1 pint	= 0.473 L
1 gallon	= 3.785 L
1 in^3/lin ft	= 53.76 cm^3/lin m
1 lb/in^2	= 6.895 kPa
1 ft^3/s	= 0.028 m^3/s
1 ft^3/h	= 0.028 m^3/h
1 gal/min	= 3.785 L/min
1 gal/min	= 3.785×10^{-3} m^3/min
1 Mgal/d	= 4.381×10^{-2} m^3/s

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Chapter I

INTRODUCTION TO INSTRUMENTATION

A. General Considerations

1. Purpose.—Dams are designed and constructed to impound storage reservoirs. They are normally the key structures of projects designed to develop a river basin for irrigation, water supply, hydroelectric power generation, flood control, recreation, navigation, and other significant economic benefits.

Dams are expected to safely withstand the potentially enormous forces created by impounded water for many years. The sudden or unplanned release of impounded water in the event of a dam failure can cause much destruction of life and property. Therefore, the proper and safe functioning of dams is an extremely important matter of public safety as well as economics.

The potential loss of life, damage to property, concern for public welfare, and negation of planned benefits caused by a dam failure make it imperative that means be available for gathering information to assess dam performance and safety. Continuing assurance of a dam's safety is necessary during construction, during first filling of the reservoir, and during long-term operation of the dam. Effective instrumentation monitoring can help assess the safety of a dam and provide this assurance. Its purpose is to complement an adequate dam safety inspection and surveillance program and to provide a major portion of the necessary information on structural behavior.

2. Need.—The usual factors or quantities that must be monitored in embankment dams are structural displacements, deformations, settlement, seepage, piezometric levels, and interstitial (pore) pressures within the structure and its foundation. The reasons for using instrumentation can be grouped into four general categories: diagnostic, predictive, legal, and research.

a. *Diagnostic Reasons.*—(1) *Verification of design.*—Normally, engineers cannot be absolutely certain that their design is both safe and the most economical approach to a project. It is common to proceed with construction using the "observational method," which assumes a design is not complete until construction is complete. Instrumentation often plays a major role with observations during construction. It enables engineers to determine the suitability and adequacy of the design as the construction progresses.

Information gathered by instrumentation also helps modify purely theoretical treatments by incorporating the effects of actual field conditions. Dam design generally entails a rigorous and sometimes complex study of forces, based on conservative assumptions concerning material characteristics and structural behavior. These assumptions are made to provide for unknowns or uncertainties in the design. However, observations from instrumentation monitoring systems and assessments of the influences on the structural performance of the dam can help mitigate these unknowns and, thereby, lead to progressive refinements and improvements in analysis techniques and future designs.

(2) *Verification of Suitability of New Construction Techniques.*—Most new or modified construction techniques are not well accepted by the construction or engineering professions until proven satisfactory on the basis of actual performance. Data obtained from instrumentation can help evaluate the suitability of new or modified techniques.

(3) *Diagnosing the Specific Nature of an Adverse Event.*—If a failure, partial failure, or severe distress occurs at a damsite, data from an instrumentation system will likely be valuable in determining the specific nature of the event. In addition, instrumentation is often installed just before or just after remedial work at a site to determine the effectiveness of the improvements.

(4) *Verification of Continued Satisfactory Performance.*—An instrumentation system that consistently yields data indicating that the dam is performing in a satisfactory manner may at first appear unnecessary. However, such information may prove valuable if some future variation in data indicates a possible problem. In addition, a consistently satisfactory performance is valuable to consider in future design efforts.

b. *Predictive Reasons.*—Using instrumentation data as it accumulates is important for informed, valid predictions of future behavior of the dam. Such predictions may vary from satisfactory performance to severe future distress, which may threaten life or safety and necessitate remedial action.

c. ***Legal Reasons.***—Valid instrumentation data can be valuable for reasons ranging from the simple determination of actual fill placement quantities for contruction pay estimates to the establishment of an information data bank for later use in possible litigation. Damage claims arising from dam construction or from adverse events can reach many millions of dollars. Instrumentation data can help determine fill placement quantities (e.g., at Arthur Watkins Dam[1]) and causes of adverse events, so that proper legal adjudication can be accomplished.

d. ***Research Reasons.***—Advancement of the State of the Art.—Studying the performance of a dam and the instrumentation data generated from it affords a better understanding of the complexity of the many forces acting, usually interdependently, on a dam and provides quantifiable information for future designs. Such research has led to advances in construction techniques, to improved and innovative design concepts, and to a better understanding of failure mechanisms.

We are normally interested in measuring variations in three principal properties during the life of an embankment dam. These properties are the resistance to water movement, resistance to deformation, and strength characteristics. Unfortunately, neither the physical properties of a structure nor the external natural forces acting on it vary independently of each other. This makes clear cause and effect relationships difficult to identify. Such relationships become apparent only as the amount of data secured by measurements becomes rather large.

Damage to an embankment is commonly attributed to one or more of the following:

- Excessive seepage through and possible internal erosion of the embankment or its foundation
- Longitudinal cracking caused by differential settlement along the interface between embankment zones
- Deterioration and clogging of drainage systems
- Loss of integrity of the core caused by settlement-induced cracking
- Overtopping of the embankment caused by unusually high reservoir inflow or by inadequate spillway capacity
- Perpendicular cracking caused by differential settlement between the embankment and steep abutment-foundation contacts and hydraulic fracturing.

Instrumentation can be expensive to install and securing measurements can be very time consuming. Therefore, limiting the amount and kind of instrumentation used and the frequency with which measurements are secured is necessary. No simple rules determine the quantity, exact type, or location of instrumentation needed at a site. These determinations remain a matter of experienced judgment based on common sense and intuition.

3. **Instrumentation Philosophy.**—Ideally, instruments used in a given situation should have the following characteristics:

- Sufficient accuracy
- Long-term reliability
- Low maintenance requirements
- Compatibility with construction techniques
- Low cost
- Simplicity

Compatibility with construction techniques involves both minimizing impacts on construction operations and maximizing the likelihood that the instrument will actually be satisfactorily installed. Realistically, when selecting a specific instrument type for use in a given situation, the optimal balance of the above, often-conflicting characteristics is sought.

Before starting a monitoring program, the roles and responsibilities of all involved in the design, in the acquisition of equipment, and in the reading, maintenance, and interpretation of data must be established. These positions must be adequately staffed and funded. Monitoring programs should be developed to answer specific questions. If there are no questions to be answered, there is no need for the monitoring program.

All participants in the instrumentation monitoring program must be well trained in what is being monitored and why. Personnel who realize the importance of their efforts will perform better. Never just explain "how to do a task," explain "why" because a mistake anywhere in the process can render the data meaningless. And meaningless data can be worse than no data at all because it may lead to erroneous actions being taken.

Because a large percentage of anomalies are caused by instrument or human error, those personnel responsible for instrumentation must be trained in determining whether the instrumentation is functioning

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[1] Arthur V. Watkins Dam is a zoned earthfill structure, 36 feet high and 76,665 feet long, located northwest of Odgen, Utah.

satisfactorily. This may require backup systems and periodic maintenance or calibration. Data should be acquired by trained and skilled personnel and not just the lowest ranking or temporary employees.

Though the measurements themselves are important, sometimes just as important are seemingly unrelated things that may enable one to determine cause and effect relationships for data (i.e., precipitation, excavation rate, embankment soil properties, etc.). These relationships are much more evident when looking at plotted data rather than columns of raw data.

The entire instrumentation effort must be a conscientious and meticulous effort because even one instrument reacting anomalously can be of the utmost importance. Anomalous behavior cannot be ignored just because it occurred for only one instrument.

As discussed in section 2, there are many reasons for installing instrumentation in both new and existing dams. The question of number, type, and location of instruments at a dam can be addressed effectively only by the fortuitous combination of experience, common sense, and intuition. Most dams represent unique situations and therefore require unique solutions for their instrumentation requirements. The instrumentation system design must be conceived with great care and with consideration for the site-specific geotechnical conditions at the dam. In general, an adequate but cost effective instrumentation installation at a new dam will constitute approximately 1 percent of the total construction cost of the dam. In unusual circumstances, this cost can be as high as 2 to 3 percent of the construction cost.

4. Minimum Desirable Instrumentation.—In 1978, a team was assembled within the USBR (Bureau of Reclamation) to study the question of minimum instrumentation of dams. The task of determining the minimum instrumentation needed to ensure the safety of dams was divided into two categories, existing dams and new dams, because each has unique problems. Some of the important differences noted were:

- New dams usually require more monitoring to demonstrate safety during construction, first filling, and early age.
- Some options for installing instruments are available during construction but not for existing structures.
- Prolonged drought may have desiccated the water barriers of some old dams creating cracks through which seepage water can flow.
- Many old dams have been built using design, construction, and performance standards significantly different from those built under the current state of the art.

The team determined that the factors of greatest importance to the safety of embankment dams and their spillways and outlet works are quantity and source of seepage, differential and total earth movements, water levels, pore pressures, and water quality.

As a result of the team's efforts and subsequent policy reviews, it was determined that new dams should be designed to contain the appropriate number of quality, optimally located, state-of-the-art instruments, to assess dam safety for a long-time period consistent with engineering design and economic constraints. It was also determined that existing dams should be retrofitted with instrumentation as dictated by relative need on a site-specific basis.

5. Safety Evaluation of Existing Dams.—**a.** ***Instrumentation.***—The fact that an existing dam contains minimal or no instrumentation is not, in itself, an adequate reason for installing instrumentation there. Much more substantive reasons (e.g., severe hazard, visually noted distress, visually noted stress, or anomalies in geologic or construction records) must be present to justify installing and monitoring instrumentation. This philosophy has resulted in a greater cost effectiveness in the overall USBR mission. In fact, certain types of instrumentation that must be installed by drilling holes in the embankment can endanger the facility. The USBR's goal is to use instrumentation as a major tool in an ongoing commitment to dam safety.

b. ***Inspection.***—In 1978, the USBR initiated the SEED (Safety Evaluation of Existing Dams) Program and with it a comprehensive training program for examining and evaluating the safety of existing dams. A manual [10]* was prepared to provide engineering and technical personnel at all levels of Government and private engineering organizations with sound, comprehensive guidelines and procedures for the examination and evaluation of dams. To supplement the SEED Manual, a training program was developed for personnel responsible for dam safety.

A SEED formal inspection team consists of experienced civil and mechanical engineers and geologists. Each team is normally led by an engineer assigned to the Division of Dam Safety. Other team members may

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*Numbers in brackets refer to entries in Chapter VIII—Bibliography.

include regional personnel, individual consultants, other Division of Dam Safety staff members, project personnel, and representatives from other Federal and State agencies, who may join the team for the onsite examination.

The SEED inspection team makes a comprehensive review of all data pertinent to the safety of the dam, performs an onsite examination, analyzes all data and findings, updates a data book, and prepares a written Examination Report for the Chief, Inspections Branch. Findings, conclusions, and recommendations relative to the safety of the dam are presented.

B. Pressure Measuring Devices

6. Purpose.—Excessive pore-water pressures in either the embankment or in the foundation directly affect the stability of the dam. Devices used to measure pressure include various types of piezometers and total pressure cells. Piezometers are commonly used for measuring water pressures that may be induced by embankment loading during construction of a dam.

Piezometers are also used to measure the water pressure and phreatic surface caused by seepage in relatively pervious portions of embankments and foundations. Such measurements can be critical because of possible piping or other seepage-induced instability conditions, such as the presence of excess hydrostatic uplift pressures. Piezometers may be designed to operate either as a closed system or as an open system.

Total pressure cells are used to monitor total static pressure acting on a plane surface. These cells help define the magnitude of major stresses in earth embankments and against pipelines, dam control structures, building foundations, and retaining walls.

7. Types.—Many styles and types of pressure measuring devices have become available over the years. The closed system devices include the HPI (hydrostatic pressure indicator), hydraulic TTP (twin-tube piezometer), GP (pneumatic piezometer), VWP (vibrating-wire piezometer), pneumatic TPC (total pressure cell), and other electrically operating piezometers. The open system devices include the PTP (porous-tube piezometer), SPP (slotted-pipe piezometers), and OW (observation well). The devices used in USBR facilities are discussed in detail in this publication. The advantages and limitations of various piezometer types are indicated in table 1-1.

C. Seepage Measuring Devices

8. Purpose.— Seepage through, around, or below an embankment dam is a valuable indicator of the condition and continuing level of performance of a dam. The quantity of seepage entering a seepage collection system is normally directly related to the level of the water in the reservoir. Any sudden change in the quantity of seepage collected without apparent cause, such as a corresponding change in the reservoir level or a heavy rainfall, could indicate a seepage problem. Similarly, when the seepage water becomes cloudy or discolored, contains increased quantities of sediment, or changes radically in chemical content, a serious seepage problem is likely. Moisture or seepage appearing at new or unplanned locations on the downstream slope or below an embankment also may indicate a seepage problem.

9. Types.—Quantitative devices, including weirs, flowmeters, Parshall flumes, and calibrated catch containers are commonly used for measuring seepage. Geophysical methods used for qualitative seepage analysis include thermotic surveys and self-potential measurements.

The weir is one of the oldest, simplest, and most reliable devices used to measure the quantity of flow of water. The critical parts of weirs can be easily inspected, and improper operation can be easily detected and quickly corrected. The weirs normally used are the 90° V-notch, the rectangular, or the trapezoidal (Cipolletti) types. The quantity discharge rates are determined by measuring the vertical distance from the crest of the overflow portion of the weir to the water surface in the pool upstream from the crest. The discharge may then be computed by formula or by reference to tables.

A Parshall flume is a specially shaped open-channel flow section. The discharge may be computed or determined by reference to tables and charts prepared with the throat width of flume, the upstream head, and the downstream head as variables.

Table 1-1.—Comparison of piezometer types, advantages, and limitations.

Characteristic	Piezometer type			
	Open-standpipe	Hydraulic	Pneumatic	Vibrating-wire
Length of time in use	Long	Long	Short	Very short
Precision of data	Moderate	Low	Low	High
Time lag in impervious soils	Long	Short	Very short	Very short
Cost — Drill hole installation	Inexpensive		Expensive	Most expensive
Cost — In new dam embankment or foundation	Moderate	Moderate	More expensive	Even more expensive
Construction interference in new dams	Substantial	Minimal	Minimal	Minimal
Complexity of installation	Very simple	Moderate	Complex	Moderate
Complexity of reading and maintenance	Very simple	Significant maintenance	Readings moderately complicated	Very simple
Potential for problems with installation	Fairly low	High (problems develop with age)	High	Very low
Central reading location?	No	Yes	Yes	Yes
Restrictions on central reading location?		Yes (elevation)	Yes (distance)	No
Time required for reading	Long	Moderate	Fairly long	Very short
Read negative pore pressures?	No	Yes	No	Yes
Other considerations	With high water levels — can have freezing problems. Porous-tube piezometer filter can plug due to repeated water inflow and outflow.	If maintenance not done regularly, lines will plug	Must prevent humid air from entering tubing	Sensitive to temperature changes

Calibrated containers may be used to measure low flow quantities from a pipe outlet. The time required to fill a container of known volume is measured and the flow is computed (usually in gallons per minute).

Flowmeters and pressure transducer devices are sometimes used to determine the quantity of flow in a pipe or open channel.

Thermotic survey techniques may in special instances help identify zones of high permeability and groundwater flow concentrations within fractured rock and alluvial deposits. Although these techniques do not replace borings or the need to install conventional instrumentation, they may be valuable in directing the location of more quantitative investigation methods, such as drill holes and pumping tests.

Self-potential or streaming potential surveys may be useful in the detection of discrete seepage paths, which tend to render conventional piezometer data inadequate.

D. Internal Movement Measuring Devices

10. Purpose.—The measured internal movements of dams consist principally of vertical movements and relative horizontal movements caused mainly by the low shearing strength or the long-term creep strain of the foundation or embankment materials. Internal movements do, of course, result in external movement of the dam's crest or side slopes.

Typical conditions where the installation of vertical movement devices would be advisable include:

- Foundations containing compressible clays or relatively loose deposits of silts, silty sands, or sandy materials
- Foundations containing heterogeneous or lenticular soil deposits that include compressible soils
- Zoned embankments containing soils of significantly different compaction and consolidation characteristics
- Embankments adjacent to appurtenant concrete structures, such as spillways
- Deep excavations in fine-grained soils or shales where rebound or heave is likely to occur resulting in later recompression during dam embankment construction

In general, the need to measure vertical movement increases as dams increase in height and volume because greater loading results in correspondingly greater settlement than that for lesser dams on similar foundations.

To provide data that are readily interpreted, measuring both the vertical and the horizontal components of movement at one or more locations may be necessary. This is most often accomplished by using inclinometers, which are discussed in detail in sections 51 and 52.

Internal movement devices are important during construction to detect zones or areas of excessive settlement or horizontal movement, which are indications of stability problems or differential movements that could result in cracking. These devices are also used to provide data for pay quantities related to large settlements and to evaluate control of fill placement and strength gain caused by consolidation.

11. Types.—A number of devices for measuring internal movements are available. The devices currently in use or being considered for use by the USBR are the IVM (internal vertical movement), baseplate, PSS (pneumatic settlement sensor), VWSS (vibrating-wire settlement sensor), inclinometer, tiltmeter, MPBX (multipoint borehole extensometer), shear strip, and radiosonde (Idel) devices. All of these devices are discussed in detail in chapter IV.

E. Surface Movement Measuring Devices

12. Purpose.—External vertical and horizontal movements are measured on the surface of embankments through the use of level and position surveys of reference points. Reference points may be monuments or designated points on the crest, slopes, or toe of the embankment or on appurtenant structures.

Detecting surface evidence of slope stability problems during construction is of primary importance. Such evidence includes slope bulging, sagging crests, foundation heave at or beyond the toes, and lateral spreading of foundations and embankments.

During dam operation, lateral translational or rotational movements from forces caused by pool loading, reservoir drawdown, and the effects of seepage pressures are required to help evaluate safe performance.

The movements of structures adjacent to, on, or in embankments (such as conduits, bridges, and spillways) are measured to evaluate embankment and foundation distress and to evaluate the behavior of the structures themselves.

13. Types.—Devices commonly used for measuring external movement consist principally of reference points and targets set in structural concrete off the structure, steel bars embedded in the embankment (embankment measuring points), and reference marks or points on structures. Measurements are made using conventional surveying equipment, including levels, theodolites, rods, calibrated survey tapes, and EDM (electronic distance measuring) devices.

F. Vibration Measuring Devices

14. Purpose.—Vibration or seismic instrumentation is used to record the responses of a structure, foundation, and abutments to seismic events. Major vibrations at a damsite could cause liquefaction of the foundation soils or the embankment, resulting in potential stability problems or the cracking of concrete slabs or other structures. The vibrations could be caused by earthquakes or by construction (rehabilitation) related vibrations (from blasting or construction equipment).

The measurement of earthquake motion can help improve the designs of future dams (so that they can better resist earthquake effects) and help assess damage after significant earthquake occurrences. Because of the inability to predict exactly when or where earthquakes will occur, it is desirable to install instruments for most structures in areas of high earthquake incidence and for other structures where embankments or foundation materials could liquefy during seismic action. The measurement of construction-induced vibration can help control construction activity near a dam.

15. Types.—The general term, seismograph, refers to all types of seismic instruments that write a permanent, continuous record of earth motion. The basic components of a seismograph include a frame anchored to the ground, one or more transducers, timing devices, and a recorder. As the frame moves with the ground, the transducers respond according to the principles of dynamic equilibrium. Signals of horizontal motion in two planes and vertical motion may be sensed either electrically, optically, or mechanically. The motion sensed may be proportional to acceleration, velocity, or ground displacement.

The variety of commercially available instruments include the strong-motion accelerograph, peak recording accelerograph, seismoscope, and others.

G. Record Tests

16. Purpose.—Testing the embankment and foundation materials adjacent to instrumentation installations is necessary to determine the characteristics of those materials. Instrument performance is most directly influenced by the soil materials adjacent to the instruments. Therefore, these materials are subjected to a "record" testing program, which is normally performed by USBR personnel. In general, additional tests on materials adjacent to virtually all instruments would be desirable. However, practical economic limitations dictate that only those tests pertinent to the physical property being measured be performed. Data from these tests become a permanent part of the file on each instrument installation.

17. Types of Tests.—Record tests include basic index property determinations, such as grain-size analyses, specific gravity tests, and Atterberg limit tests. In addition, field density determinations, percolation or permeability tests, and consolidation tests are frequently performed. The following are examples of guidelines that have been used for record testing on USBR projects.

a. ***Internal Movement Measuring Devices.***—Two field density tests should be made for each unit of every internal vertical and horizontal movement device. One test sample should be obtained from the soil near the bottom of the trench excavated for each crossarm, vertical plate, or baseplate unit, and the other test sample should be obtained from the compacted trench backfill after it has been brought to grade.

When all or part of a dam is founded on highly compressible materials, representative undisturbed samples for consolidation testing should be obtained in the foundation at the vertical movement and baseplate installations, unless suitable samples have been obtained previously. However, consolidation tests are not normally required when the internal movement measuring devices are placed on rock. In weak materials, undisturbed samples should be taken so that laboratory strengths of the inplace materials can be determined.

b. ***Piezometer Installations.***—A field density test is required at each embankment piezometer tip. This test should be made within the rolled fill at the tip location before the offset trench for the tip is excavated. Where feasible, each hole drilled for foundation-type piezometer tips should be logged throughout its length, and a record sample should be obtained from the soil at the bottom of each hole, where the foundation porewater will be contacted.

In addition to field density tests on embankment materials and in-place density tests on foundation materials, gradation analyses, specific gravity tests, liquid limit and plastic limit tests, and permeability tests should be performed on all samples.

Sufficient material for additional tests must be obtained during the density test sampling. Before testing, foundation samples should be sealed to prevent the loss of moisture. The record samples obtained from the foundation piezometer locations should contain representative material taken from the location of the piezometer tip. The size of the sample obtained will, of course, depend on the drilling and sampling equipment used to excavate the holes.

The embankment field moisture and density conditions must be duplicated for the permeability test, and in-place conditions must be maintained for the tests on foundation materials. Therefore, all stored samples should be properly labeled and referenced to the appropriate density test. Special care should be exercised to attain a high level of accuracy in all record tests.

18. Record Test Reporting.—Record tests at locations of internal movement measuring devices should be designated as "record rolled," "record tamped," or "undisturbed," depending on the condition or construction history of the material tested. The results of all tests on all samples should be submitted with the Final Report on Earth Dam Instrumentation.

H. Monitoring Schedules

19. General.—Instruments should be installed within an embankment dam to assess the performance and safety of the structure both during construction and over the long term. Periodic readings of the instruments are required to accomplish this goal. Continuing analysis and review of these readings can indicate unusual structural behavior and possible problems.

Internal movement device readings should be studied for significant vertical or horizontal movements. Piezometers should indicate the pattern of seepage flow through the embankment and foundation. During construction, piezometer readings should be observed for the development of excessive pore-water pressures. Observations made immediately after a severe drawdown of the reservoir provide information on pore-water pressures retained within and under the structure. Changes in pore-water pressures and internal or external movement reflect stress conditions within the embankment that influence the stability of the structure. Because behavior conditions originate during construction and vary continuously throughout operation, instrumentation data can be valuable to construction and operating personnel, as well as to design and dam safety engineers.

The processing of large amounts of raw data can be handled efficiently using current computer technology. The interpretation of the data requires careful examination of measurements and of other influences, such as reservoir operation, air temperature, precipitation, drain flow and leakage around the structure, seasonal shutdown during construction, and instrument operation.

During construction of an embankment dam, two types of reports are required for reporting embankment dam instrumentation. Monthly instrumentation reports (L-15), distinct from other construction reports, must be prepared in duplicate and sent to the Structural Behavior Branch (D-3350) during the construction of the dam. A suggested title for these reports is "Progress Report on Dam Instrumentation—Month of ____________, 19__, ____________Dam." These reports should include the following information concerning instrumentation work done during the previous month:

1. A short narrative describing workstatus and work performed
2. Discussion of any problems and/or abnormalities encountered
3. Discussion of instances where contract specifications or drawings were modified or deviated from
4. Pictures of instrumentation work, as appropriate
5. As-built information on newly installed instruments
6. Completed data reporting forms for periodic readings of instruments during construction

The "Final Report on Dam Instrumentation" (L-16) is to be prepared upon completion of dam construction and is intended to provide a complete and concise record concerning the actual construction of the instrumentation. Two copies of this report should be sent to the Structural Behavior Branch within 2 months following completion of dam construction. This report should include the following:

1. Documentation of the materials and equipment actually installed, including manufacturer, model number, calibration data supplied by the manufacturer, and other relevant information. This documentation should cover as much of the materials and equipment as possible, including seemingly routine items such as bentonite, PVC pipe, etc.

2. Records of preinstallation testing of equipment.
3. Drill logs for holes drilled for instrument installations.
4. Description and discussion of problems or abnormalities encountered during instrumentation-related work.
5. Description and discussion of instances where instrumentation contract specifications and drawings were modified or deviated from.
6. Description and discussion of any contractor claims concerning the instrumentation work.
7. Photographs of instrumentation work.
8. "As-built" information on all instrument installations. A copy of the instrumentation drawings should be marked with all appropriate "as-built" modifications and included in this report. Particular attention must be paid to the numbers and information shown on the instrumentation tables or drawings.
9. Actual instrumentation pay item quantities.
10. Records of maintenance and/or repair of instruments performed since acceptance of instruments.
11. Comments, criticisms, suggestions, etc., concerning the layout, design, installation, or any other aspect of instrumentation facilities. To be most useful, statements on this subject should identify and describe the problems encountered and describe, as specifically as possible, any recommended changes.
12. Any other information that would be useful in documenting the construction of instruments at the dam.
13. All instrumentation data taken during construction of the dam. Copies of completed data reporting forms previously submitted in L-15 reports are satisfactory for this purpose.

20. Variations in Schedule.—Monitoring schedules for instruments vary depending upon the purpose of the instrument, previous data obtained, any special circumstances that have been discovered, and the dam status (e.g., the dam has yet to be constructed, is under construction, has recently been constructed and the reservoir is in first filling, is in normal post-first filling operation). Monitoring schedules are established by oral or written requests from designers before the beginning of dam construction. The construction considerations establish reading schedules during construction and the filling criteria set the schedules during the first reservoir filling. After first reservoir filling has been completed, the standard form titled "Schedule for Periodic Readings" (L-23) is used to establish instrument reading frequencies. Table 1-2 gives some typical reading frequencies that are representative of what might be requested for various instruments at various stages in a dam's life.

Should special circumstances arise at a dam, additional instrument readings, beyond what the above reading schedules dictate, should be taken as necessary to fully monitor and document the situation. Examples of such special circumstances include unusual reservoir operations (rapid drawdown, unusually high reservoir levels, etc.), seismic activity in the area, unusual changes in instrumentation readings, the development of new seepage areas, etc. Changes in the reading schedule are made by the Structural Behavior Branch.

21. Emergency Procedures.—If the safety of a dam is endangered and a failure or impending failure condition exists, it is extremely important that dam personnel immediately follow the prescribed procedures exactly. Each dam has a set of prescribed procedures listed in its SOP (Standing Operating Procedures). These procedures cover such occurrences as earthquakes, embankment or abutment cracking, new springs or seeps, changes in quantity or color of seepage water, landslides, and abnormal instrument readings. Proper compliance with emergency procedures requires that instrument readers be diligent, alert, and very conscientious in reporting all unusual situations.

I. Maintenance and Performance

22. General.—All instrumentation, such as piezometers, inclinometers, and accessory equipment such as tips, valves, and gauges, should be inspected and calibrated over their expected operating range soon after delivery so that defects can be corrected before installation. Plastic tubing should be checked for type and size tolerances and pressure tested before use. Removable equipment should be recalibrated at regular intervals.

To properly monitor the performance of a dam, collecting instrumentation data over extended periods is necessary. Thus, the equipment must be as simple, rugged, and durable as possible, and it must be maintained

Table 1-2.—Frequency guidelines for reading various instrumentation systems[1]

Instrument type	During construction		During first filling	Periodic report—operations	
	Construction	Shutdown[2]		First year	Regular[3]
Hydrostatic pressure indicators					Quarterly
Hydraulic twin-tube piezometers (separate gauges)					Quarterly
Hydraulic twin-tube piezometers (master gauges)					Annually on same date as separate gauge readings
Pneumatic piezometers	Twice monthly	Monthly	Twice weekly	Monthly	Monthly
Vibrating-wire piezometers	Twice monthly	Monthly	Twice weekly	Monthly	Monthly
Carlson pore-pressure cells	Twice monthly	Monthly	Weekly	Monthly	Monthly
Total pressure cells (vibrating-wire, pneumatic, other)	Monthly	Monthly	Weekly	Monthly	Quarterly
Porous-tube piezometers	Twice monthly	Monthly	Twice weekly	Monthly	Monthly
Slotted-pipe piezometers	Twice monthly	Monthly	Twice weekly	Monthly	Monthly
Observation wells	Twice monthly	Monthly	Twice weekly	Monthly	Monthly
Seepage measurement devices (weirs, flumes, etc.)	Monthly	Monthly	3 Times a week	Monthly	Monthly
Geophysical seepage measurements	As required	As required	As required	As required	As required
Internal vertical movement devices	Complete set of readings each time a unit is installed	Monthly	Montly	6 Months after completion	6-year intervals
Foundation baseplate settlement	Complete set of readings each time a unit is installed	Monthly	Monthly	6 Months after completion	Annually
Pneumatic settlement sensors	Monthly	Monthly	Monthly	1 Month after completion	Annually
Vibrating-wire settlement sensors	Monthly	Monthly	Monthly	1 Month after completion	Annually
Inclinometers (horizontal and vertical movements)	Complete set of readings each time an extension is added	Usually monthly but could be as often as weekly	Monthly	Monthly	Annually or semi-annually
Multi-point extensometer	Monthly	Monthly	Monthly	1 Month after completion	Monthly or quarterly
Shear strips	Monthly	Monthly	Monthly	3 Months after completion	Annually
Radiosonde methods	Monthly	Monthly	Monthly	6 Months after completion	Annually
Tiltmeters	Monthly	Monthly	Monthly	3 Months after completion	Quarterly
Embankment measurement points	At time of installation	At 6-month intervals until first filling	At 3-month intervals normally, but sometimes monthly	6 Months after completion	3 to 6-year intervals
Structural measurement points	Monthly as portions are completed	Monthly	Monthly	6 Months after completion	3 to 6-year intervals
Vibration measurement devices	As construction progresses if blasting is conducted	Continous readings	Continous readings	Continous readings	Continous readings
Water quality testing	Monthly if required	Monthly if required	Monthly if required	Monthly if required	Monthly if required

[1] All entries indicate a minimum frequency of readings. Readings may be required more frequently (even daily) for certain installations.

[2] Weather permitting.

[3] When there are no apparent problems at the facility.

[4] These devices are no longer being installed in USBR dams.

in satisfactory operating condition. However, maintaining proper operational characteristics is difficult. For example, even a simple surface settlement point is subject to damage by frost action on the downstream slope, by wave and ice action on the upstream slope, by traffic and road maintenance operations on the crest, and by vandalism in many forms. Observation wells and many types of piezometers can be damaged by frost action, caving, corrosion of the casing materials, the loss of measuring equipment in the hole, and by vandalism. Unless special precautions are taken, the average life of these installations may not exceed 5 years.

To minimize damage, the tops of measuring points and wells should be as inconspicuous and as close to the surrounding surface as possible. Installations should be located away from roads, trails, or water channels, and noncorrosive materials should be used where possible. They must, however, be marked so that they will be visible to maintenance personnel.

The problems of providing for continuous satisfactory performance are significantly greater for apparatus permanently buried in the embankment or in the dam foundation. In the past, some of the plastics considered for use as tubing between piezometer tips and the pressure gauges for hydraulic piezometers were so brittle that they almost always cracked during installation. In addition, some plastics have a slight permeability to air and water that precludes their effective use in some piezometer installations. And certain plastics act as semipermeable membranes absorbing moisture from the surrounding soil.

Certain microbes may proliferate within hydraulic piezometer tubes unless the water in the system is treated with a biological inhibitor. In the past, some antifreeze solutions placed in systems developed a floc, resulting in plugging of the tubes. In certain environments, some gauge materials may corrode, making them useless.

To reduce the length of tubing between the measuring points and the gauges and to protect the equipment associated with the hydraulic piezometer gauge system from the environment, the terminal equipment is normally placed in a well chamber 20 to 30 feet deep. These wells must be ventilated to remove dangerous gases before the gauge reading personnel enter. However, if these wells are ventilated for an extended period on a very cold day, the terminal equipment may be damaged by freezing, and if the well does not have proper drainage, it may flood. Furthermore, the atmosphere in a closed well can be very humid, allowing corrosion to proceed rapidly. Other piezometer systems do not require deep well installations and therefore are subject to fewer problems of this type. Engineers' awareness of the problems associated with the use of various materials and instrumentation devices coupled with a better knowledge of the environment, has led to modifications in designs, installation procedures, and operating instructions. Many suggestions concerning specific modifications are included later in this manual.

23. **Performance Checks.**—Some devices, such as probes and reading devices, are removable and may be calibrated regularly. However, much of the instrumentation at a dam is fixed in place and not repairable. Generally, these fixed devices can be replaced only from the surface by devices installed in drilled holes. Other devices such as surface monuments are, of course, readily replaceable.

24. **Calibration of Devices.**—At the request of a regional office, a project office, or one of its own reviewers, the Structural Behavior Branch will replace or recalibrate equipment that is defective or suspected to be faulty.

Pressure gauges for hydraulic or pneumatic piezometers are routinely calibrated before field use. Inclinometer systems (probes and readout devices) are checked in a hole of known inclination before field use and rechecked periodically. When new instruments (gauges, readout units, and piezometers) are purchased, the manufacturer's certificate and calibration should be obtained to ensure that gauge factors and other important details are known before preinstallation testing in the field.

Before installation, all piezometers should be tested for proper response to a known pressure. These tests should include examining pneumatic piezometers for air leaks, checking the vibrating-wire piezometer manufacturer's gauge factor, checking the factory saturation of ceramic stones for proper air removal and bubbling pressures for pore diameter verification, and checking total pressure cell plates for leaks. These tests are usually performed at the jobsite, but in some cases may be performed at the E&R (Engineering and Research) Center.

J. Data Acquisition, Processing, and Review Procedure

25. **General.**—Acquisition and processing of a vast amount of data are necessary to maintain effective monitoring of USBR embankment dams. Currently, over 225 dams are monitored to varying degrees. This

results in over 1,000,000 points of data being handled and processed by the Embankment Dam Instrumentation Section of the Structural Behavior Branch each year. The goals of the processing and review procedure are the accurate and timely evaluation of data relating to the safety of the facility.

The continuing process by which instrumentation data are acquired and handled and the resulting final action taken may be grouped into the five phases listed below (fig. 1-1). See appendix B for detailed procedures for data processing.

a. ***Data Acquisition.***—Instrumentation data are obtained from readings and observations by water district or USBR field personnel. The data should be acquired on a monitoring schedule (Form L–23) that can accommodate each instrument type at every dam. An example of a typical completed Form L–23 is shown on figure 1-2.

Data must be collected according to the established schedules. Delays in transmitting data to the reviewing office should be minimized because timelines can be critical. This goal may be accomplished by various methods. Where reasonably possible, ADP (automatic data processing) methods should be used to transmit data. Where remoteness, volume of data, or other reasons preclude ADP methods, delays caused by preparation of transmittal letters or data reduction, to transmission and retransmission to intermediate offices, or to merely allowing data to sit around collecting dust must be avoided, and the reviewing office must review data promptly when they are received. The concept of timeliness must consider the entire process; i.e., it does no good to save a few hours during one step of the process if it adds days to another step.

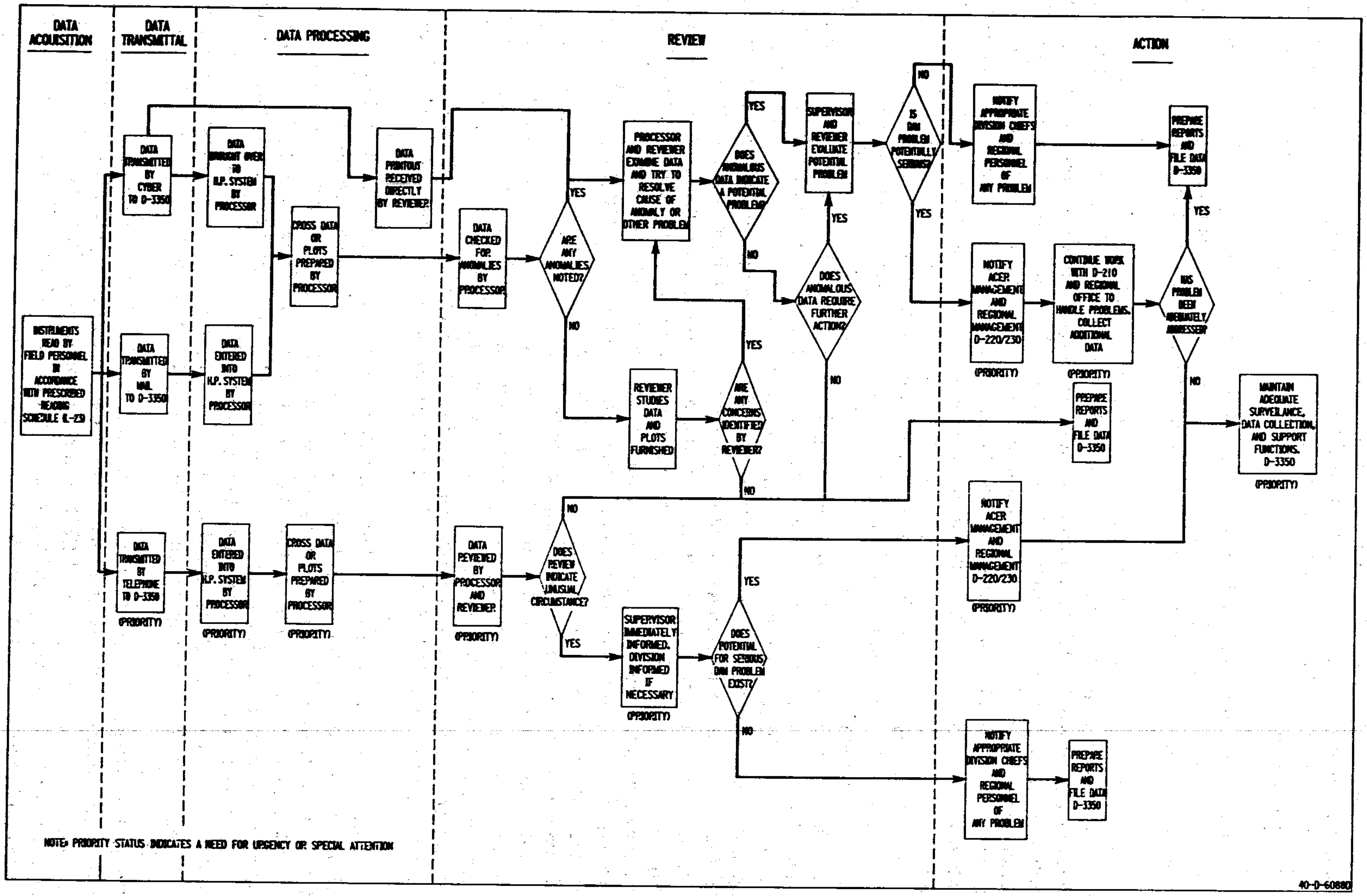
Instrumentation data are usually recorded manually on a field data form for later transmittal to the Structural Behavior Branch. (A few examples of field data forms are presented later in this manual.) However, a relatively recent development in field data acquisition involves the use of a portable teletranslational computer (fig. 1-3). Data acquisition personnel are now using this equipment at 15 dams, and usage is planned for additional dams. To use this device, the instrument reader enters the field data directly into its memory. Prior readings for each instrument may be stored in the device and displayed upon request. After the instrument readings are entered, the data in the device may be loaded into a computer terminal for transmission to the Structural Behavior Branch in Denver. When these data are transmitted, the receiving office automatically receives the data sent and a comparison with the most recent previous data. All mathematical computations required are performed by the computer program. Computer entry should allow more rapid, more timely, and more accurate data acquisition and transmittal. The less often data are transcribed, the less chance there is for error. USBR instructional manuals have been developed for field personnel on the use of portable teletranslational devices and for computer data transmittal.

b. ***Data Transmittal.***—All instrumentation data are transmitted to the Structural Behavior Branch (code D–3350) at the E&R Center in Denver, Colorado. Data may be sent by mail or transmitted directly to the CCS (Central Computer System) through remote terminals and telephone links. When computer communication is not available, special priority data for critical dams may be transmitted verbally by telephone on a frequent schedule (even daily) to the Structural Behavior Branch. A few dams are scheduled to have their data transmitted automatically via GOES (Geostationary Operational Environmental Satellite) directly to the E&R Center.

Data accuracy is essential. Poor data are of less value than no data and may even lead to inappropriate actions being taken. Elimination of errors is the responsibility of every individual dealing with the data. Data collectors must be alert to avoid mistakes in reading, recording, and transcribing data. When data are transmitted by means other than mail, the transmitting office must make at least a cursory review to eliminate errors and to note and communicate information on real anomalies that have occurred. These checks and reviews must be accomplished within a time frame that does not affect the timeliness of the transmittal to the reviewing office. Inconsistent readings noted by the reviewing office must be reconciled in the most efficient manner. This will often mean direct communication with the reader or, in some cases, the intermediate transmitting office.

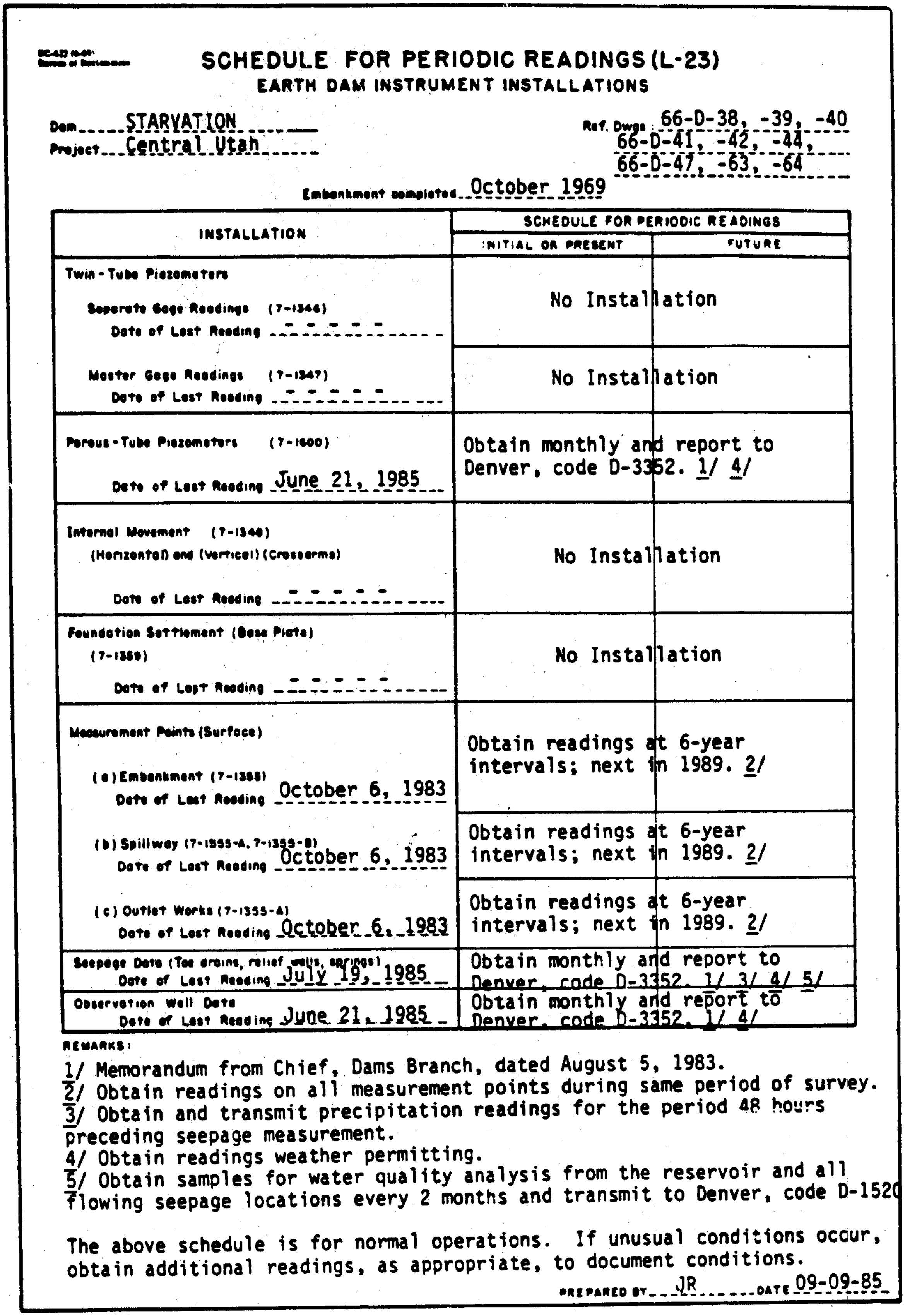
c. ***Data Processing.***—Regardless of the method of transmittal, all data received are entered into the computer system at the Structural Behavior Branch. The data processing is performed by the Branch's engineering technicians. Data received by the CYBER system are processed within 24 hours of the time they are entered. Data received by mail are normally processed within a week. And data received by telephone should be processed and reviewed within a few hours.

Using the computer system, the data should be periodically cross-checked against previous data. Computer graphics are used to prepare graphic presentations (plots) of the data, current reservoir level, etc. Many examples of these plots are included in succeeding chapters. The data cross-check and the generated plots



NOTE: PRIORITY STATUS INDICATES A NEED FOR URGENCY OR SPECIAL ATTENTION

Figure 1-1.—Flowchart of instrumentation data acquisition, handling, and use.



SCHEDULE FOR PERIODIC READINGS (L-23)

EARTH DAM INSTRUMENT INSTALLATIONS

Dam STARVATION

Project Central Utah

Ref. Dwgs. 66-D-38, -39, -40
66-D-41, -42, -44,
66-D-47, -63, -64

Embankment completed October 1969

INSTALLATION	SCHEDULE FOR PERIODIC READINGS	
	INITIAL OR PRESENT	FUTURE
Twin-Tube Piezometers Seperate Gage Readings (7-1346) Date of Last Reading - - - - -	No Installation	
Master Gage Readings (7-1347) Date of Last Reading - - - - -	No Installation	
Porous-Tube Piezometers (7-1600) Date of Last Reading June 21, 1985	Obtain monthly and report to Denver, code D-3352. 1/ 4/	
Internal Movement (7-1348) (Horizontal) and (Vertical) (Crossarms) Date of Last Reading - - - - -	No Installation	
Foundation Settlement (Base Plate) (7-1359) Date of Last Reading - - - - -	No Installation	
Measurement Points (Surface) (a) Embankment (7-1355) Date of Last Reading October 6, 1983	Obtain readings at 6-year intervals; next in 1989. 2/	
(b) Spillway (7-1555-A, 7-1355-B) Date of Last Reading October 6, 1983	Obtain readings at 6-year intervals; next in 1989. 2/	
(c) Outlet Works (7-1355-A) Date of Last Reading October 6, 1983	Obtain readings at 6-year intervals; next in 1989. 2/	
Seepage Data (Toe drains, relief wells, springs) Date of Last Reading July 19, 1985	Obtain monthly and report to Denver, code D-3352. 1/ 3/ 4/ 5/	
Observation Well Data Date of Last Reading June 21, 1985	Obtain monthly and report to Denver, code D-3352. 1/ 4/	

REMARKS:

1/ Memorandum from Chief, Dams Branch, dated August 5, 1983.
2/ Obtain readings on all measurement points during same period of survey.
3/ Obtain and transmit precipitation readings for the period 48 hours preceding seepage measurement.
4/ Obtain readings weather permitting.
5/ Obtain samples for water quality analysis from the reservoir and all flowing seepage locations every 2 months and transmit to Denver, code D-152

The above schedule is for normal operations. If unusual conditions occur, obtain additional readings, as appropriate, to document conditions.

PREPARED BY JR DATE 09-09-85

Figure 1-2.—Typical completed Form L-23, Schedule for Periodic Readings.

Figure 1-3.—Portable teletranslational computer. P801-D-81004.

are delivered to a designated reviewer, a professional experienced and knowledgeable in the field of geotechnical instrumentation and embankment dam behavior. (see fig. 1-1.)

d. *Data Review.*—First, data processors review the data for obvious anomalies and make sure that the information is correct, to the best of their knowledge. Then the designated reviewer for the dam checks each data set for anomalies in the new data. Such anomalies may include obviously unusual readings or data trends that, at least on the surface, do not conform with previous trends. The vast majority of anomalies noted result from human error in the acquisition, transmittal, or processing of the data.

Potential dam problems detected by the instrumentation system are usually discovered during the data review phase. A cross-check program automatically compares new data with previous data from the same instruments. The causes of simple, obvious data errors can usually be identified quickly by contacting the person taking the reading. These errors are then corrected or a request for supplementary data is issued. If a potentially serious problem is detected, the reviewer's supervisor is consulted, and a decision made on the proper course of action. Various offices must have access to the data in one or more of its forms; i.e., raw data, processed data, plotted data, interpreted data, etc. Channels must be established to ensure that everyone with a need is provided the means to satisfy that need.

The data received are plotted on a prearranged schedule depending on the instrument type and the importance of the status of the dam. For example, plotting may be accomplished for each new data set or as infrequently as every fourth data set. However, data may also be plotted at any time upon request.

Two copies of the data plots are automatically prepared by the computer system. One copy of each plot is placed in data books kept current for reference by personnel of the Division of Dam Safety, the Division of Dam and Waterway Design, the Division of Water and Land Technical Services, and others at the E&R Center. The second copy of each plot is reviewed by the data processor and reviewer, checked for anomalies, and corrected of errors. In this phase of the review process, longer term trends or anomalies can be identified. After the data plots are considered satisfactory and representative of actual field conditions, the second copy is sent to designated responsible individuals in the appropriate USBR regional office for their review and information.

Once cross-comparisons have been made and the review process is complete, a copy of the data plots is mailed to the field office responsible for acquisition of the data. Complete feedback from the data review to the regional and field offices is critical to the success of the team effort required in the USBR's instrumentation program.

e. *Possible Actions.*—If no unusual circumstances or potential problems are detected in the data or in the potential consequences of the data, the information is filed for future reference. These data are used periodically for the preparation of Structural Behavior Reports on each dam. These reports are prepared at least every 3 years, and often more frequently.

If the potential for a serious problem is detected at a dam, the regional and ACER (Assistant Commissioner—Engineering and Research) management personnel are informed immediately and appropriate action is taken. Subsequent management level meetings are conducted to determine the proper course of action, which might include such drastic measures as emergency lowering of the reservoir. Regardless of the management decisions made, monitoring is continued at a much increased frequency until the potential problems are considered to have abated or to have become insignificant.

All phases of the data management process (transmittal, processing, and review) are obviously of great importance in dam safety. However, it must be stressed that none of these phases are of any significance unless the data acquisition phase is conducted in an accurate and timely manner by personnel sincerely interested in the safety of the facilities. The personnel collecting the data are in the ideal position to raise immediate concerns when significant anomalies occur. They play a key role in the process and should be trained accordingly.

26. Visual Inspections.—The regular visual inspection of the condition of a dam and the surrounding area by personnel familiar with the dam may be the most important factor in the continuing safety of the dam. The SEED Program (previously discussed) provides for regular formal, including visual, inspections. The required visual inspections are detailed in appendix B of the *SEED Manual* [10]. Visual inspections by the instrument readers at the regular instrument reading intervals is a valuable supplement to the SEED Program.

The instruments described in this manual will detect an impending failure only if they are appropriately located and functioning properly. Therefore, visual inspection is most vital. In many cases, visual inspections appropriately reported on field data forms explain the anomalies in the instrument readings. A proper visual inspection includes walking both sides of the crest, along both abutments, and walking a reasonable distance upstream and downstream of the dam. The principal items to watch for include:

- Cracking of the embankment in any plane or direction
- Cracking or landslide-type movements of the upstream and downstream valley walls
- Bulging of the lower portion of the embankment slopes, the abutments, or the valley walls
- Subsidence of any portion of the crest
- Sinkholes in the reservoir bottom or in the upstream face of the dam
- New boils or springs, or an increase in volume from a spring in the downstream face of the dam, the abutments, or the downstream valley walls or floor
- A persistent vortex (whirlpool) in the reservoir that is unrelated to an operational outlet works
- Seepage water that is discolored or carrying soil sediments
- Cracking in any concrete appurtenant structures

If any of these items or any other unexplainable physical occurrence is noted, the Structural Behavior Branch should be contacted immediately. Photographs of all signs of distress should be taken at regular intervals.

The frequency of visual inspections will vary greatly depending on the dam's characteristics, its age, the reservoir level with respect to previous maximum levels, and many other factors. In general, all maintenance and operations personnel at a dam should be constantly alert for signs of distress. The person at a damsite responsible for instrumentation should perform visual inspections at least at the time of instrument reading. At the many dams where snow limits access or obscures signs of distress, formal visual observations should be conducted as soon after snowmelt as possible.

Chapter II

PRESSURE MEASURING DEVICES

A. History and Development of Instruments

27. History and Development.—Instruments designed to record the water level or the pore-water pressure represent the earliest pressure monitoring devices. Such devices continue to be used universally on embankment dams. These devices have been used and developed by the USBR: from the early standpipe style of observation pipes through the use of hydrostatic pressure indicators to the current piezometer systems. This early development by the USBR is listed in [19].

a. *Observation Wells.*—Early in the history of the USBR, a need was perceived for an apparatus that could delineate the phreatic line and help determine flow patterns through earth dams and their foundations. An early attempt to provide a partial solution involved the installation of observation pipes, called "saturation pipes," at Belle Fourche Dam[1] in 1911. These 2-inch nonperforated standard galvanized iron pipes were left open at both ends (until they were capped at the surface in 1924), and the water level was read directly using a float and measuring tape; 73 such pipes were installed and later abandoned.

Observation pipes were frequently used to determine ground-water levels in pervious areas of embankments, in abutments, and in foundations. As pressure indicators, they succeeded only in special applications and indicated the true water level only in completely saturated portions of the embankment or foundation. Observation pipes are of minimal value in soils of relatively low permeability because the response to a rise in reservoir level is much too slow.

b. *Water Level Indicators.*—In 1935, WLI's (water level indicators) were developed, and 13 units were installed at Hyrum Dam[2] and 12 units were installed at Agency Valley Dam[3]. This instrument is a combination manometer and piezometer. It uses a copper screened cage (well point) filled with fine sand as a contact element. The transmitting elements are two copper tubes, one inside the other. At the pressure point, rings of holes are drilled in the outer tube. The tubes are extended to a central terminal box on the crest of the dam. The recording element consists of an air tank, Bourdon-tube gauges, and a coupling system to the inner tube from the well point.

The inner tube is open at the pressure point and air under pressure can displace the water in this tube. The pressure is read when air displaces the water in the system. This is signaled by a fluttering of the gauge pointer.

The WLI apparatus was not very accurate because all of the water in the system could not be displaced simultaneously. Moreover, the column of water in the system did not represent true pressure conditions because air was compressed in the soil voids and escaped into the larger tube. Extreme care was necessary during installation to prevent damage to the pressure point. Construction pore pressures could not be recorded because the WLI could not be installed until after a dam was completed. All of the water level indicators installed have been abandoned.

c. *Hydrostatic Pressure Indicators.*—Concurrent with the development of the WLI, the HPI (hydrostatic pressure indicator), a modification of the Goldbeck cell, was designed and installed in several dams. A typical example is the HPI installation in Caballo Dam[4] in 1938 and 1939. Details of the pressure transmitting and recording elements of the instrument are shown on figures 2-1 and 2-2. The contact element indicator is a cylindrical brass shell with a thin gold-plated monel-metal diaphragm mounted in its base. This diaphragm is secured and protected by a locknut and filter stone placed in front of the diaphragm. This filter stone keeps out the embankment soil and permits the pore pressure to act on the diaphragm. The transmitting element consists of a copper tube through which an electrical lead wire has been threaded. This wire is soldered to a contact point in the top of the indicator. A similar contact point is fixed to the diaphragm.

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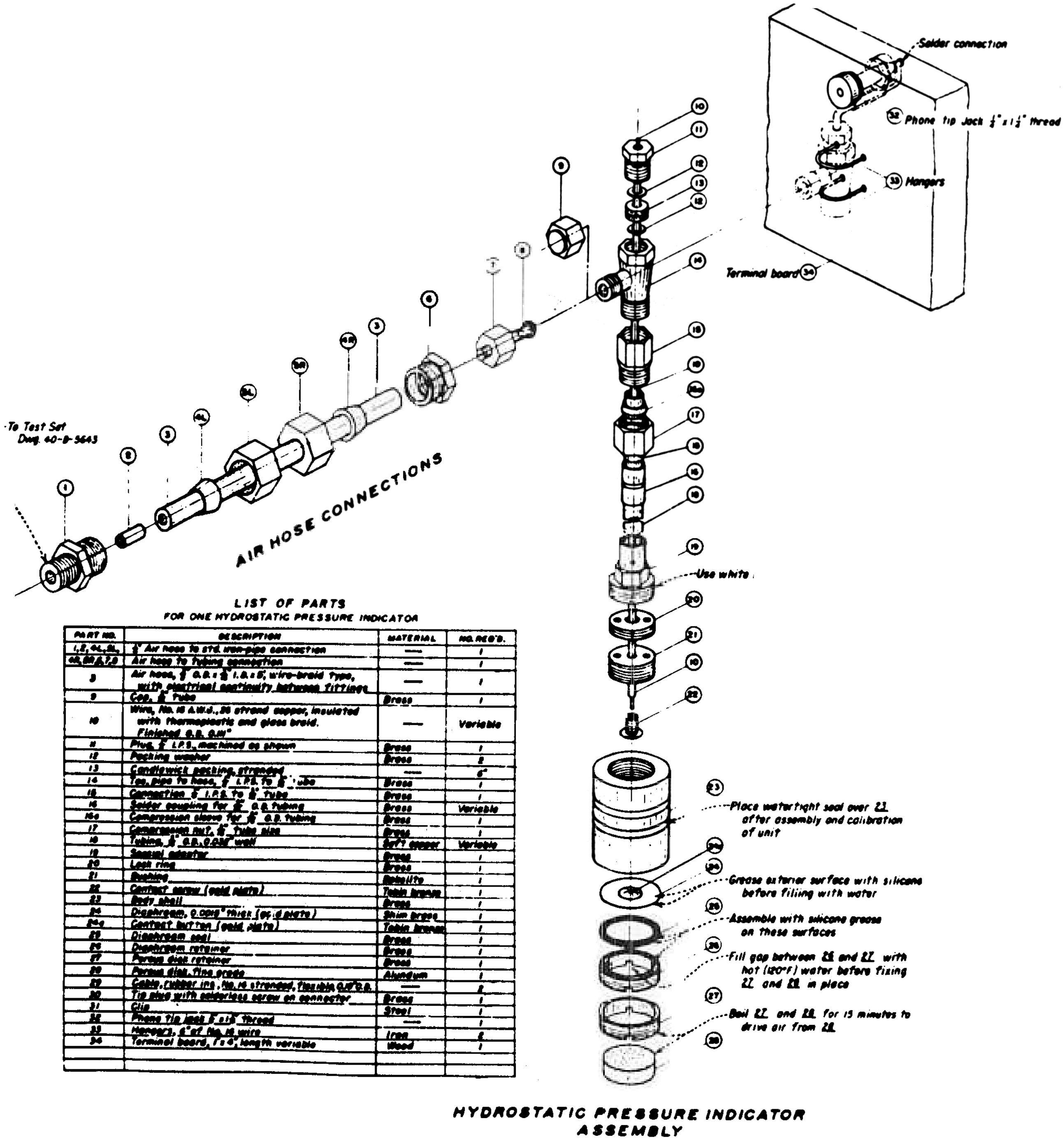
[1] Belle Fourche Dam is a homogeneous earthfill structure, 122 feet high and 6,262 feet long, located on Owl Creek in Butte County, South Dakota.

[2] Hyrum Dam is a homogeneous earthfill dam, 116 feet high and 450 feet long, located on the Little Bear River in Cache County, Utah.

[3] Agency Valley Dam is a zoned earthfill dam, 110 feet high and 1,850 feet long, located on the North Fork of the Malheur River in Malheur County, Oregon.

[4] Caballo Dam is a zoned earthfill dam, 96 feet high and 4,558 feet long, located on the Rio Grande River in Sierra County, New Mexico.



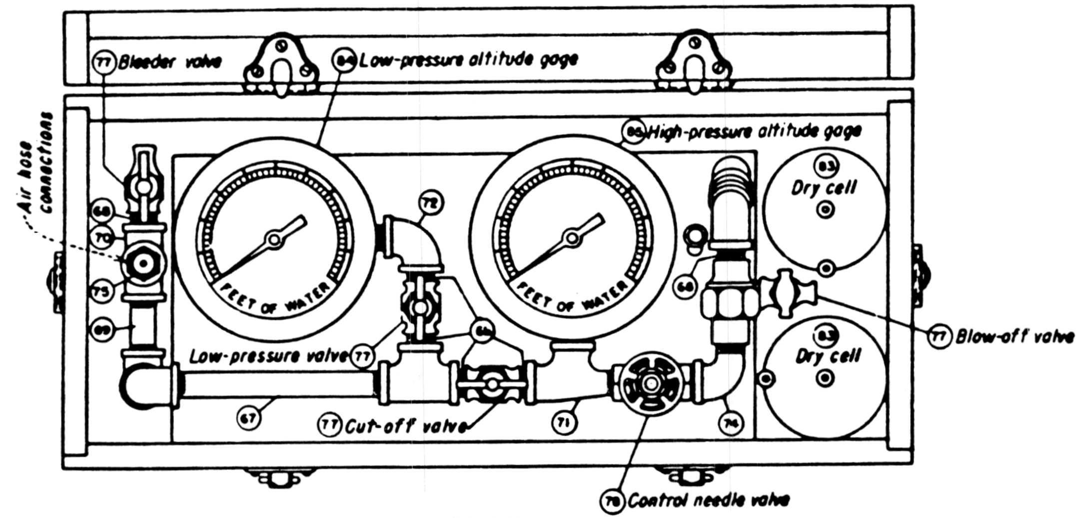
LIST OF PARTS
FOR ONE HYDROSTATIC PRESSURE INDICATOR

PART NO.	DESCRIPTION	MATERIAL	NO. REQ'D.
1, 2, 4L, 5L,	¼" Air hose to std. iron-pipe connection	—	1
4R, 5R, 6, 7, 8	Air hose to tubing connection	—	1
3	Air hose, ½" O.D. x ¼" I.D. x 5', wire-braid type, with electrical continuity between fittings	—	1
9	Cap, ⅛" tube	Brass	1
10	Wire, No. 16 A.W.G., 26 strand copper, insulated with thermoplastic and glass braid. Finished O.D. 0.11"	—	Variable
11	Plug, ⅛" I.P.S., machined as shown	Brass	1
12	Packing washer	Brass	2
13	Candlewick packing, stranded	—	6"
14	Tee, pipe to hose, ⅛" I.P.S. to ⅛" tube	Brass	1
15	Connection ⅛" I.P.S. to ⅛" tube	Brass	1
16	Solder coupling for ⅛" O.D. tubing	Brass	Variable
16a	Compression sleeve for ⅛" O.D. tubing	Brass	1
17	Compression nut, ⅛" tube size	Brass	1
18	Tubing, ⅛" O.D., 0.032" wall	Soft copper	Variable
19	Special adapter	Brass	1
20	Lock ring	Brass	1
21	Bushing	Bakelite	1
22	Contact screw (gold plate)	Tobin bronze	1
23	Body shell	Brass	1
24	Diaphragm, 0.0015" thick (gold plate)	Shim brass	1
24a	Contact button (gold plate)	Tobin bronze	1
25	Diaphragm seal	Brass	1
26	Diaphragm retainer	Brass	1
27	Porous disk retainer	Brass	1
28	Porous disk, fine grade	Alundum	1
29	Cable, rubber ins., No. 16 stranded, flexible 0.5" O.D.	—	2
30	Tip plug with solderless screw on connector	Brass	1
31	Clip	Steel	1
32	Phone tip jack ½" x 1½" thread	—	1
33	Hangers, 6" of No. 16 wire	Iron	2
34	Terminal board, 1" x 4", length variable	Wood	1

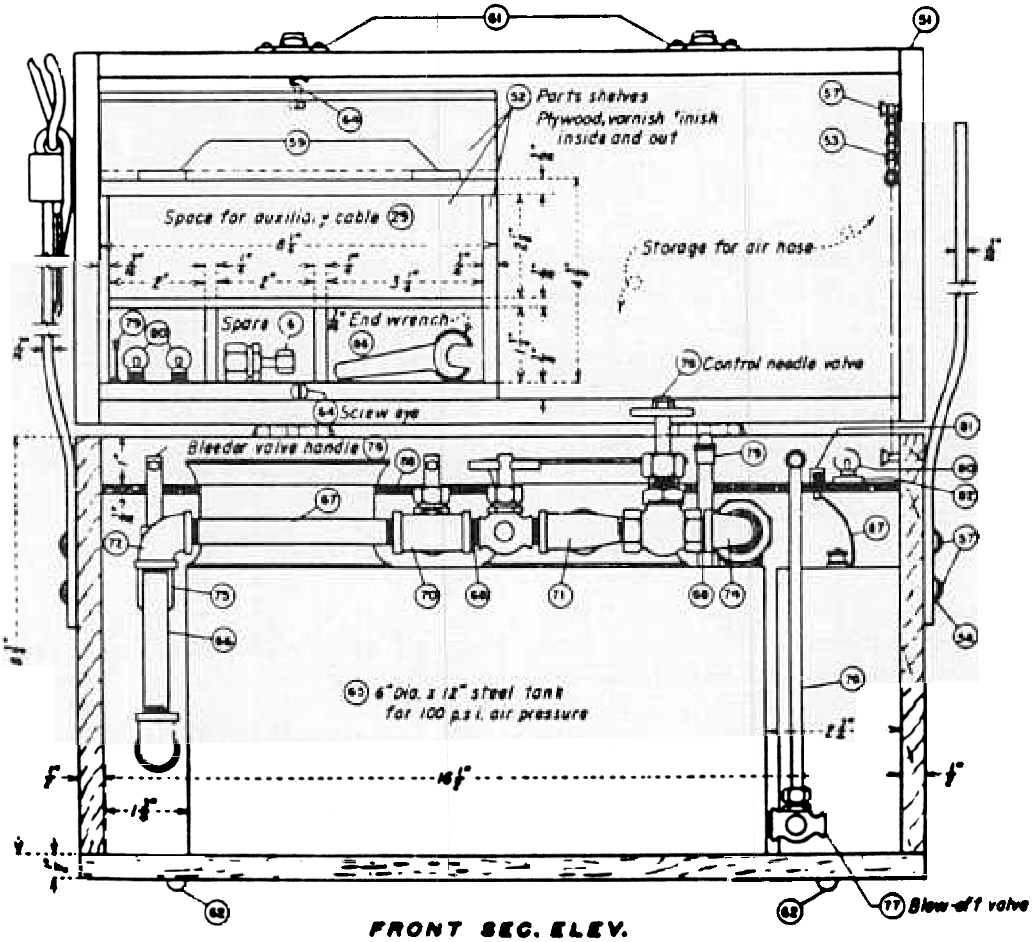
Figure 2-1.—Hydrostatic pressure indicator, assembly and details. 40-D-5642.

The recording test set uses a combined pressure and electrical system. It consists of an air pressure tank, tire pump, Bourdon-tube gauge, battery, light, and valves and couplings. The recording apparatus is temporarily coupled to the system at the terminal box on the crest of the dam. To read the HPI, air is pumped into the tubing. When the light on the panel goes off, the air pressure in the system equals the pore-water pressure. Successive "make" and "break" contacts determine the pressure, which is read directly from the Bourdon gauge in feet of water.

Several problems were found with the HPI instrumentation: It was not rugged enough to withstand normal long-term field operation. The thin metal diaphragm was easily warped or even ruptured when excessive air



PLAN



FRONT SEC. ELEV.

Figure 2-2.—Hydrostatic pressure indicator, test set. 40-D-5643.

pressure was applied. Flushing procedures for de-airing were rather complex. Galvanic cell reactions between the gold and the copper shell and the lead solder could corrode and destroy the diaphragm. Moisture from the compressed air introduced into the system could condense above the diaphragm and invalidate the reading. The instrument was costly to manufacture because very accurate machining of the operating parts, particularly the diaphragm, was required. Each instrument had to be manufactured independently after ordering, thereby hampering availability. And pore-water pressures during construction could not be obtained in early USBR installations because the instruments were installed in holes drilled into the embankment after the dams were completed.

Despite the problems encountered with the HPI, it was found to be very sensitive and had performed well. After nearly 15 years of service, approximately 70 percent of the HPI's that had been installed were still operating, and with proper care in usage, they could have given many more years of service. They did not, however, receive the necessary care. Several accessory elements, such as the housing, have now been improved with the development of a weatherproof terminal box with drains, a terminal board for the tube ends, and a steel cover. With careful redesigning, the HPI could have been developed into a more rugged, yet still accurate, instrument.

d. ***Hydraulic Piezometer Systems.***—A hydraulic piezometer system was developed to provide a more rugged instrument that could readily be installed during the embankment construction. The original installation was made at Fresno Dam[5] in 1939. The installation was designed as shown on figure 2-3; the details of the machined brass piezometer tips are shown on figure 2-4. Type A tips were installed in the embankment, and type B tips with extension pipes were installed in the foundation. The extension pipes were constructed of ¾-inch standard galvanized iron pipe and filled with sand and water. They were set in holes drilled to the required depth in the foundation.

The ¼-inch o.d. (outside diameter) copper tubing filled with water, which extends from the tip to the terminal well, transmits the pressures. A double-tube system is used so that water can be circulated through the system to flush out the trapped air and completely fill the tubes. The end of the piezometer tip contains a porous carborundum disk, which permits direct contact with pore-water pressure, but prevents soil particles from entering and clogging the system. Pressures are recorded in the terminal well on a single compound altitude Bourdon-type gauge calibrated to read feet of water. The pressure at each tip may be observed by balancing manifold pressure against actual pore pressure from the embankment or foundation. The accessory reading apparatus includes an air trap to allow air to be separated when fluid is circulated, a hand pump used to fill the system and flush the tubes connecting the recording gauge to the tips, a supplementary water supply tank, and necessary flushing valves. This equipment is normally installed in concrete-lined terminal wells at the downstream toe of the dam.

Hydraulic piezometers are simple, accurate, and rugged enough to withstand rough handling during placement and operation by even inexperienced field personnel. Many are still operational and with proper maintenance, may continue to operate for many years. At Fresno Dam, 72 piezometers were installed using brass tips and copper tubing. By 1985, 48 of these piezometers were still operating, a loss of only 33 percent over 46 years.

The copper tubing for the Fresno Dam installation was supplied in 20-foot-long coils, and considerable time was spent connecting the lengths by soldered sweat couplings. The bulk and weight of the copper tubing prevented prefabrication and necessitated assembly on the fill resulting in some significant delays in the earth placement operations.

e. ***Plastics.***—During the early 1940's, when copper products were unavailable for nonmilitary use, plastics were substituted for copper to continue the piezometer installations at several dams under priority construction. After the war, in 1946, when major construction was resumed, the shortage and relatively high cost of copper and brass forced the continued use of plastics in piezometer installations.

One of the first installations of plastic materials was in 1942 and 1943, at Anderson Ranch Dam[6]. There, plastic piezometer tips replaced the earlier brass tips, as shown on figure 2-5. The single-tube piezometer (type D) was introduced at this installation. Because a single-tube piezometer installation requires less material than a double-tube installation, it has significant economic benefits. However, the tip and tubing must be

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[5] Fresno Dam is a homogeneous earthfill dam, 110 feet high and 2,070 feet long, located on the Milk River in Hill County, Montana.

[6] Anderson Ranch Dam is a zoned earthfill dam, 456 feet high and 1,350 feet long, located on the South Fork, Boise River in Elmore County, Idaho.

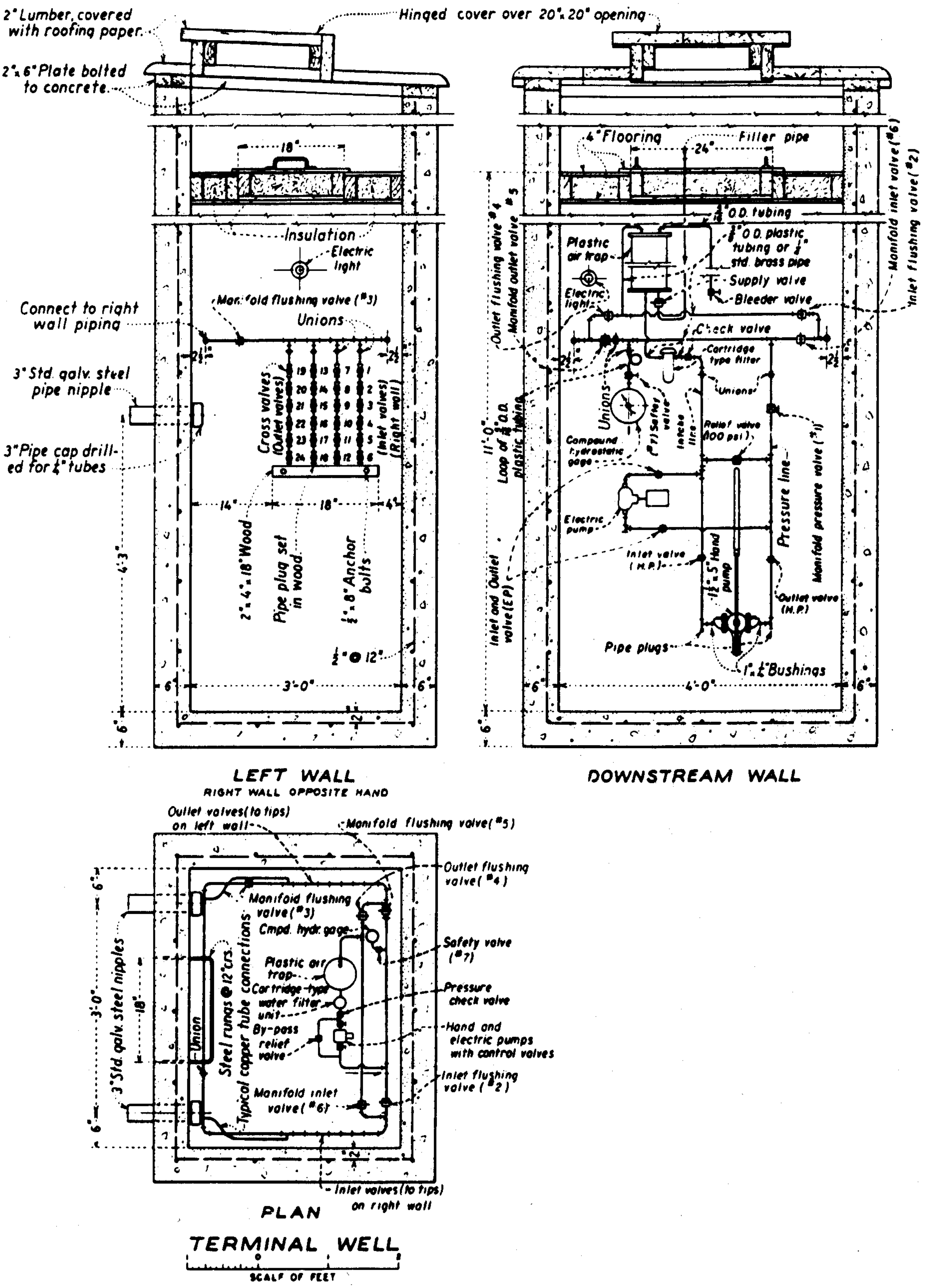
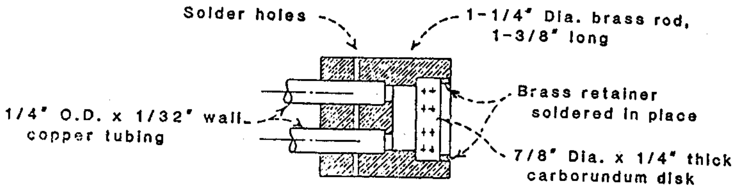
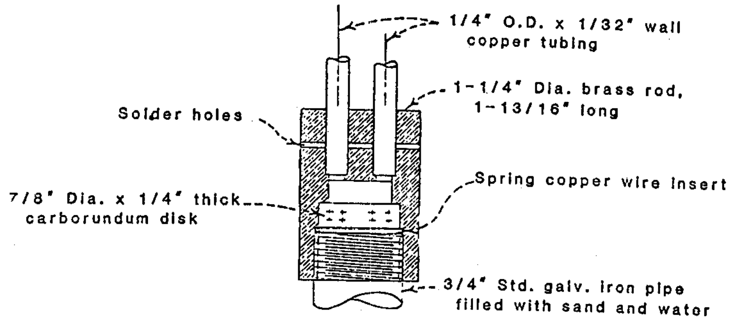


Figure 2-3.—The initial hydraulic piezometer system installation, Fresno Dam, Montana. 16-D-439.



EMBANKMENT TIP
(TYPE A)



FOUNDATION TIP
(TYPE B)

Figure 2-4.--Machined brass piezometer tips.

flushed before embedment, possibly delaying earthfill operations. Nevertheless, properly installed single-tube piezometers have continued to produce satisfactory data.

The recording system at Anderson Ranch Dam utilized a small gauge on each inlet tube and a common Bourdon-tube master gauge. Readings on the small gauges are continuous, but readings on the master gauge are made by balancing manifold readings against expected embankment pressures. All the accessory recording apparatus are housed in a terminal well on the downstream toe of the dam.

The first plastic piezometers were machined from Plexiglas and the tubing was extruded from Saran plastic material. When leads of Saran tubing were cemented into place, a crazing, or internal cracking, often occurred in the Plexiglas tips. Moreover, the Saran tended to become rather brittle at a low temperature. For these reasons, Saran and Plexiglas plastics were replaced by a cellulose acetate butyrate known as Tenite II, which could be easily molded into piezometer tips and extruded into tubing. The first installation incorporating this plastic was at Dixon Canyon Dam[7] in 1946 and 1947. (Details of the piezometer tips are shown on figures 2-6 and 2-7.) For these piezometer tips, the tubes extend from the sides of the body instead of the top, and the recess in the tips is cone-shaped rather than flat. These modifications were adopted to help eliminate the trapping of air in the tip and to eliminate turbulence during pumping. The tubing size was changed from ¼-inch o.d. to 5/16-inch o.d. to reduce the side-wall friction and surface tension of the fluid during flushing operations.

Two types of tips were developed using Tenite II: the foundation type (fig. 2-6) and the embankment type (fig. 2-7). The foundation type was different from the embankment type in that it had the lower skirt of the body extended so that a plastic extension pipe could be cemented to it. Several commercial plastic sleeve-type couplings were developed to join lengths of plastic pipe or plastic tubing.

Because of the high water loss coefficient of Tenite II (2.4×10^{-4} in^3/lin ft per hour) and its extremely sensitive osmotic reaction with solutions of ethylene glycol antifreeze, the use of Tenite II tubing was discontinued and the use of oriented standard medium hardness Saran plastic tubing was begun. Installations then used piezometer tips and extension pipes made from Tenite II, and tubing made from Saran plastic. Recording systems consisted of individual gauges mounted across inlet and outlet tubes so that pressures could be noted without disturbing the system.

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[7] Dixon Canyon Dam is a zoned earthfill dam, 240 feet high and 1,265 feet long, a unit of the Colorado Big Thompson Project.

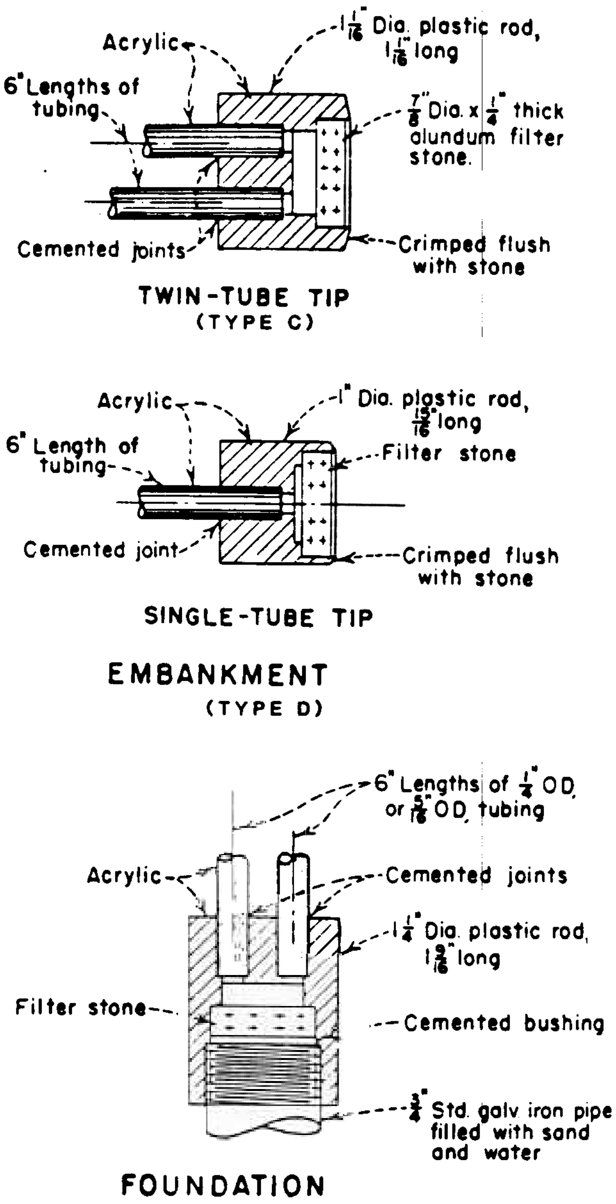

Figure 2-5.—Plastic piezometer tips.

The Saran plastic tubing is joined by standard brass compression tube fittings. Flare couplings made of both brass and plastic were tested and determined to be unsatisfactory. Producing a suitable flare on the 1/16-inch wall thickness tubing was found to be extremely difficult: Brass flare couplings tended to shear the plastic tubing and plastic couplings broke when the connection was tightened.

During the 1950's, the USBR successfully used polyethylene tubing at seven dams. Of the 223 polyethylene piezometers installed, 188 are still operating—a 16 percent loss over approximately 30 years. Polypropylene, which was developed by plastic manufacturers in the early 1960's, provided better strength characteristics than polyethylene and less air permeability than Saran tubing. Polypropylene tubing has now been used in 3 dams, and most of the 195 piezometers installed are still in operation.

f. ***Porous Disks.***—During the 1950's, the USBR also investigated the effect of varying the porosities of the carborundum disks (stones) used in the hydraulic piezometer tips. The porosity was increased or decreased at various elevations in the embankment to reduce the entry of air from the pore pressure entering the piezometer fluid lines. This shortened the time required to remove the air from the hydraulic lines. The pore sizes varied from 60 to 240 microns.

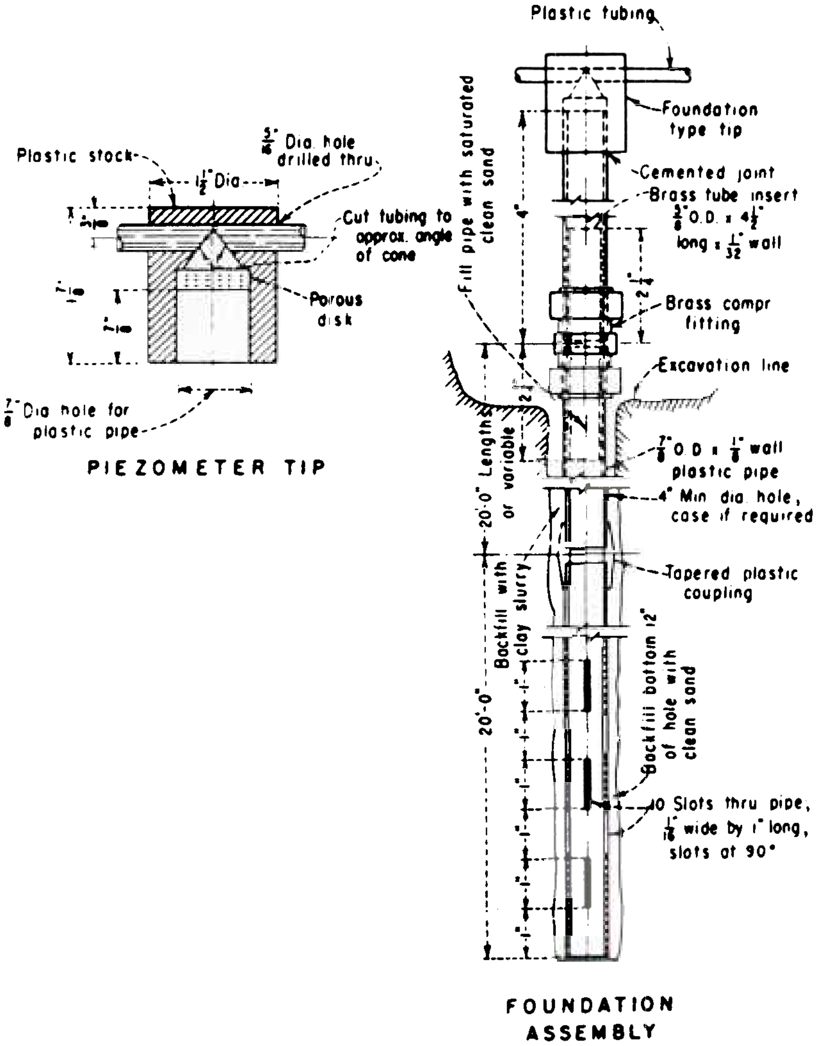

Figure 2-6.—Tenite II foundation piezometer tip and assembly. 101-D-294.

In 1959, the carborundum disks were replaced with ceramic filter disks at selected locations at Steinaker Dam[8] and at selected locations at Sherman Dams[9] to determine whether these filters would be more effective in stopping the air from entering the hydraulic lines. The 1.1 to 2.2 micron pore sizes of the ceramic disks were smaller than the pore sizes previously used. However, no appreciable difference in pore pressure was observed from that of the piezometers using the coarser carborundum disks at the same locations. Ceramic disks were also used at Merritt Dam[10] with the same effect. All subsequent hydraulic piezometers installed by the USBR have used ceramic disks, as shown on the piezometer tip drawing on figure 2-8.

28. Development of Current Practice.—The piezometer apparatus commonly used during the late 1970's has been found easily adaptable to various site conditions and sufficiently accurate for measurements of pore pressures in earth embankments. Plastic tubing, although not as resistant to accidental cutting or to heat as copper, has generally been found to be more economical, lighter, more resistance to most chemicals, more able to withstand greater external loads without collapse, and more readily available in long lengths than copper tubing. The plastic tubing installations are now giving satisfactory service, and the pore pressures

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[8] Steinaker Dam is a homogeneous earthfill dam, 162 feet high and 1,997 feet long, located on Steinaker Draw in Uintah County, Utah.
[9] Sherman Dam is a homogeneous earthfill dam, 134 feet high and 4,450 feet long, located on Oak Creek in Sherman County, Nebraska.
[10] Merritt Dam is a zoned earthfill dam, 126 feet high and 3,222 feet long, located on the Snake River in Cherry County, Nebraska.

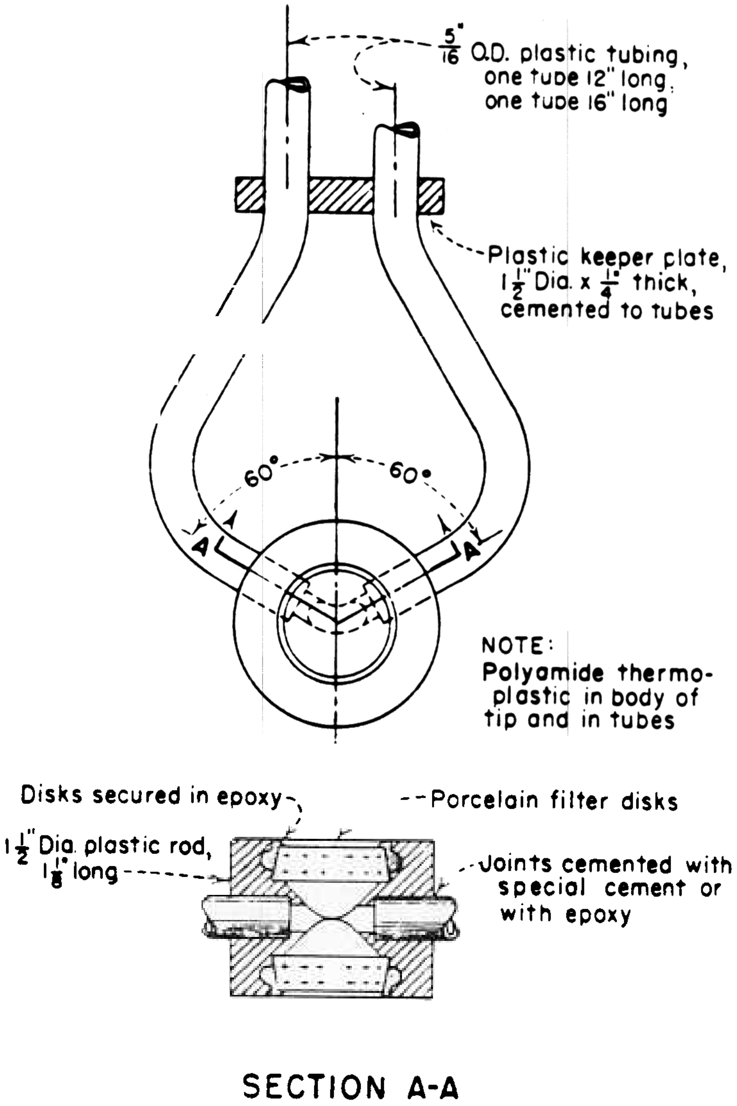

Figure 2-7.—Tenite II embankment piezometer tip.

measured show excellent continuity with construction and reservoir operation. The size of tubing used was usually 5/16-inch o.d. with a 1/16-inch wall thickness. As a general rule, the smallest possible size is desirable, but if tubing has too small a diameter, high pump pressures are encountered when water is circulated. A 5/16-inch o.d. tubing has been found to perform satisfactorily.

The piezometer systems now being installed in USBR dams use pneumatic pressure or a vibrating-wire transducer to measure pore-water pressures. Pneumatic piezometers have been installed in eight dams and are planned for three other dams now under construction. Vibrating-wire piezometers have also been installed in seven dams and are planned for four other dams under construction.

Careful consideration and selection of instruments and components to be used are very imporant. For example, in "closed system" piezometer systems such as pneumatic or vibrating-wire installations, discussed in sections 31 and 32, porous stone piezometer tips must be used with care when installed in unsaturated fine-grained soils where negative pore pressures may be developed. Within such an environment, the negative pore pressures may tend to remove water from the porous stone, possibly creating an air void within the instrument. In that case, bubbling pressures must be greater than the negative pore pressure of the surrounding environment in order for the instrument to remain fully functional. However, it should be noted that, except in special applications, the measurement of negative pore-water pressure in the field is of little practical significance.

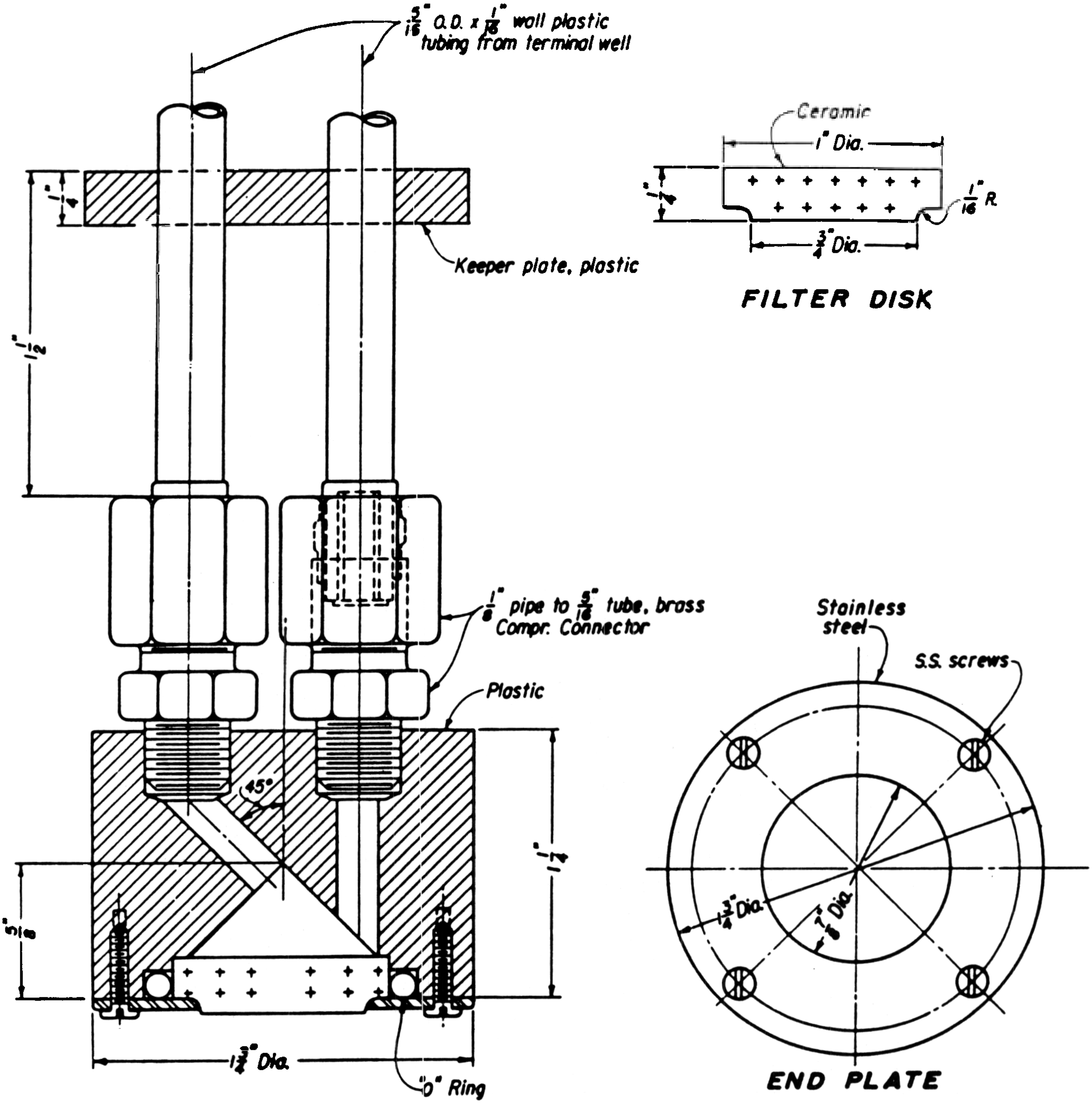

Figure 2-8.—Foundation piezometer tip with ceramic filter disk. 101-D-497

Personnel involved with the installation and operation of piezometric systems commonly develop strong opinions on the accuracy and the performance characteristics of categories of piezometer types. These opinions are often based largely on experience limited to certain types of installations. Nevertheless, the USBR believes it unwise to widely use a new product before it has been completely tested and evaluated over several years. Therefore, the USBR has had excellent success with most types of instrumentation and maintains a leading role in research on new instrumentation systems.

B. Closed System Instrumentation

29. Hydrostatic Pressure Indicators.—The HPI (hydrostatic pressure indicator) device is no longer being installed in USBR dams; however, this section is included because a few of these devices are still in use.

a. *Usage.*—Hydrostatic pressure indicators have been installed in dams since 1938. Although there are now 621 HPI's in 13 USBR dams, Bull Lake Dam[11] and Caballo Dam are the only dams where HPI readings are still being recorded. The other installations have been abandoned, mostly because of failure of the instruments or a lack of faith in the resulting data. As discussed in section 27-c, hydrostatic pressure indicators represent an earlier stage in the USBR's development of closed system piezometers.

b. ***Advantages and Disadvantages.***—The HPI devices produced very accurate and dependable information early in their life, but later deterioration of data quality usually led to abandonment. Installation of HPI's was discontinued because of the following disadvantages:

- Drilling the vertical installation holes in the embankment was expensive.
- Data on pore-pressure buildup during dam construction could not be obtained because construction had to be completed before drilling for instrument installation could begin.
- The diaphragm in the indicator often warped resulting in incorrect readings. This warping was usually caused by the use of excessive compressed air pressure when taking readings.
- The diaphragms often corroded from the moisture in the compressed air. This made the indicator useless.
- The instrument was difficult and costly to construct and to install.

c. ***Description of Equipment.***—HPI's consist of a piezometer tip assembly, terminal board, indicator box, and ¼-inch o.d. copper tubing. The piezometer tip assembly and other details of the pressure transmitting and recording elements are shown on figures 2-1 and 2-2.

d. ***Installation.***—Upon completion of a dam embankment, HPI's were installed in vertical holes drilled into the embankment. Copper tubing was then directed into a terminal box on the dam crest where all instruments could be read.

e. *Monitoring Procedure.*—At the readout location, pneumatic pressure is applied against the diaphragm through the copper tube attached to the piezometer. When the electrical contact is broken by the pneumatic pressure, which returns the diaphragm to its original shape, the readout light goes off, and the pneumatic pressure is read on the Bourdon gauge. A second reading is obtained by releasing a small amount of air pressure until the contact recloses, turning on the light. These two readings are then averaged to obtain the pressure reading used. Variations between the two readings are usually within 2 feet of water for properly functioning piezometers. HPI's are normally read monthly.

f. *Maintenance.*—Maintenance for the buried devices is impossible. The only maintenance that can be performed is occasional calibration of the Bourdon gauges and of the electrical and air pressure components of the readout device.

g. ***Data Processing.***—Pressure readings from each HPI are recorded in feet of water on form 7-1360, as shown on figure 2-9, and transmitted to the Structural Behavior Branch at the E&R Center. Upon arrival, the data are processed, reviewed, and reported, as discussed in section 25.

30. Hydraulic Twin-Tube Piezometers.—a. *Usage.*—Hydraulic TTP's (twin-tube piezometers) measure pore pressures in embankment dams and in their foundations. These devices have been installed in 53 USBR dams, beginning at Fresno Dam in 1939, and most recently in Sugar Pine Dam[12], which was designed in 1978 and completed in 1981. Nearly 2,800 TTP's were installed during this period, many of which have been abandoned because of breakage or plugging problems.

b. ***Advantages and Limitations.***—The principal advantages in the use of TTP's are a long experience record with the devices, a shorter time lag in reading than with standpipe piezometers, and the ability to use a central observation system. In addition, TTP's have a limited capability to read negative pore-water pressures and are less prone to construction damage than standpipe piezometers when installed in areas where embankment construction is taking place.

The disadvantages of the use of TTP's include a significant failure rate, freezing and other water-related maintenance problems, the need for the terminal house to be deeply embedded at the toe of the dam (because tubing lines should not be significantly higher than the piezometer tip elevation), delays to earthwork construction during installation, somewhat complicated annual maintenance techniques requiring specialized training, and the requirement for periodic maintenance, which may be complicated by flooding of low elevation terminal wells. Normally, extra expense is incurred for the construction of a separate, rather complex terminal

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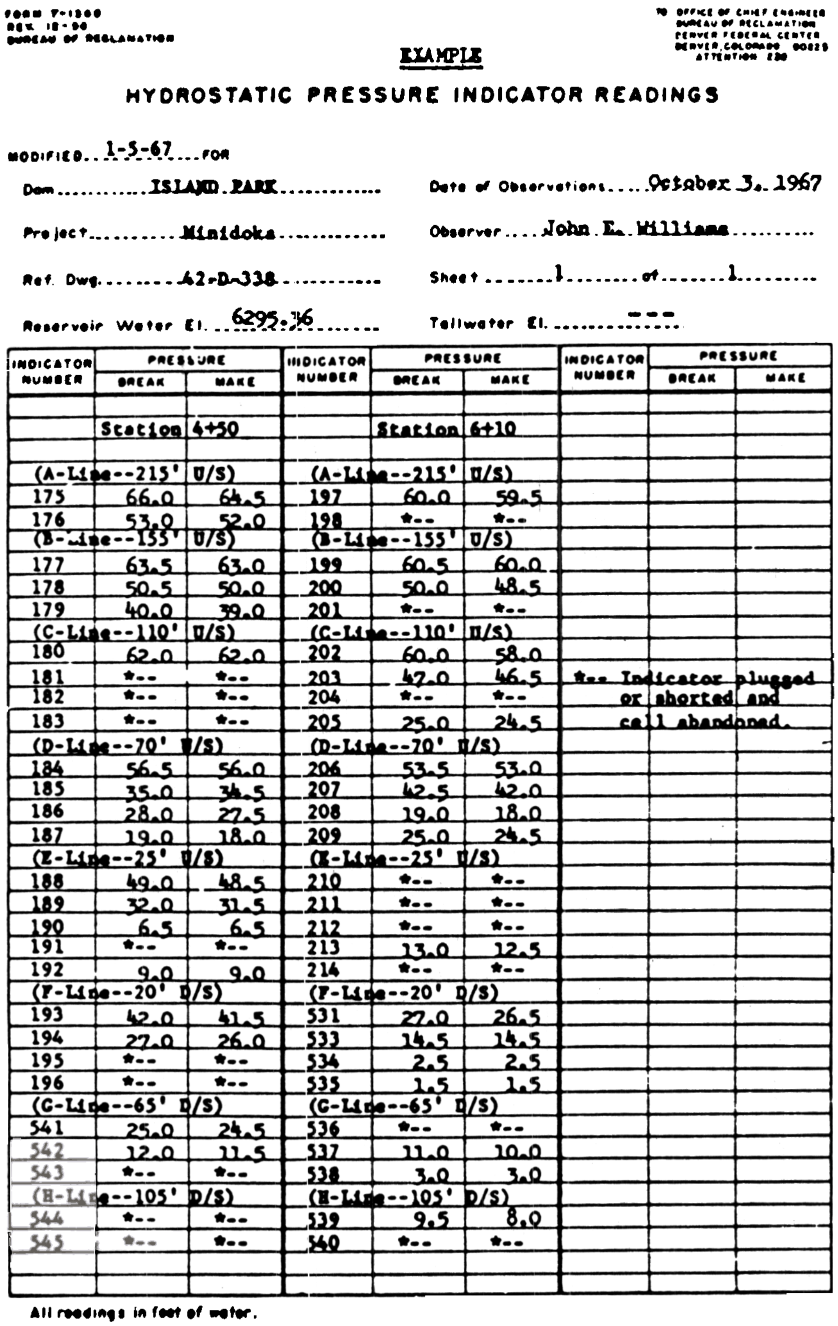
[11] Bull Lake Dam is a modified homogeneous earthfill dam, 81 feet high and 3,456 feet long, located on Bull Lake Creek in Fremont County, Wyoming.

[12] Sugar Pine Dam is an earth and rockfill structure, 197 feet high and 689 feet long, located on Shirttail Creek in Placer County, California.



FORM 7-1360
REV. [illegible]
BUREAU OF RECLAMATION

TO OFFICE OF CHIEF ENGINEER
BUREAU OF RECLAMATION
DENVER FEDERAL CENTER
DENVER, COLORADO 80225
ATTENTION [illegible]

EXAMPLE

HYDROSTATIC PRESSURE INDICATOR READINGS

MODIFIED 1-5-67 FOR

Dam ISLAND PARK

Date of Observations October 3, 1967

Project Minidoka

Observer John E. Williams

Ref. Dwg. 42-D-338

Sheet 1 of 1

Reservoir Water El. 6295.36

Tailwater El. ---

INDICATOR NUMBER	PRESSURE		INDICATOR NUMBER	PRESSURE		INDICATOR NUMBER	PRESSURE	
	BREAK	MAKE		BREAK	MAKE		BREAK	MAKE
	Station	4+50		Station	6+10			
(A-Line--215' U/S)			(A-Line--215' U/S)					
175	66.0	64.5	197	60.0	59.5			
176	53.0	52.0	198	*--	*--			
(B-Line--155' U/S)			(B-Line--155' U/S)					
177	63.5	63.0	199	60.5	60.0			
178	50.5	50.0	200	50.0	48.5			
179	40.0	39.0	201	*--	*--			
(C-Line--110' U/S)			(C-Line--110' U/S)					
180	62.0	62.0	202	60.0	58.0			
181	*--	*--	203	47.0	46.5	*-- Indicator plugged		
182	*--	*--	204	*--	*--	or shorted and		
183	*--	*--	205	25.0	24.5	cell abandoned.		
(D-Line--70' U/S)			(D-Line--70' U/S)					
184	56.5	56.0	206	53.5	53.0			
185	35.0	34.5	207	42.5	42.0			
186	28.0	27.5	208	19.0	18.0			
187	19.0	18.0	209	25.0	24.5			
(E-Line--25' U/S)			(E-Line--25' U/S)					
188	49.0	48.5	210	*--	*--			
189	32.0	31.5	211	*--	*--			
190	6.5	6.5	212	*--	*--			
191	*--	*--	213	13.0	12.5			
192	9.0	9.0	214	*--	*--			
(F-Line--20' D/S)			(F-Line--20' D/S)					
193	42.0	41.5	531	27.0	26.5			
194	27.0	26.0	533	14.5	14.5			
195	*--	*--	534	2.5	2.5			
196	*--	*--	535	1.5	1.5			
(G-Line--65' D/S)			(G-Line--65' D/S)					
541	25.0	24.5	536	*--	*--			
542	12.0	11.5	537	11.0	10.0			
543	*--	*--	538	3.0	3.0			
(H-Line--105' D/S)			(H-Line--105' D/S)					
544	*--	*--	539	9.5	8.0			
545	*--	*--	540	*--	*--			

All readings in feet of water.
Record data to nearest 0.5 feet.

Figure 2-9.—Typical completed Form 7-1360, Hydrostatic Pressure Indicator Readings. 101-D-510.

well. The lack of "off-the-shelf" availability of the TTP devices results in high fabrication costs and increased chances of assembly errors. In addition, gauges must be replaced about every 10 years, and adequate gauges have sometimes been hard to find. These disadvantages and the desire to use simple data loggers (and otherwise automate new instrumentation systems) have discouraged the installation of hydraulic piezometers.

c. ***Description of Equipment.***—Hydraulic twin-tube piezometers measure the pore-water pressure in dam embankments and foundations by means of pressure gauges installed in terminal wells at the downstream toe of the dam. Pressure is transmitted to the pressure gauges through two water-filled tubes leading from each piezometer tip. The pore-water pressure enters the tip through a porous filter.

The twin-tube piezometer system consists of a piezometer tip with porous stone, tubing, backfill material, and terminal well equipment.

(1) *Piezometer Tip Assembly.*—Foundation- and embankment-type piezometer tip assemblies should be fabricated in accordance with the details shown on figures 2-8 and 2-10. The tip assemblies include ceramic or alundum filter disks, tip bodies and keeper plates, O-rings, and a metal screen. Cloth filter bags and identification tags should also be furnished. Suggested specifications for piezometer tip assemblies are in Specification EDI-1 (Embankment Dam Instrumentation) in appendix A.

(2) *Tubing.*—The USBR has used five different types of tubing in hydraulic twin-tube piezometer installations:

- Copper tubing: ¼-inch o.d. by 1/32-inch wall thickness. Between 1939 and 1942, 341 piezometers using copper tubing were installed in seven dams. This tubing has performed very well, but is not recommended because of its high initial expense.
- Tenite II plastic tubing: cellulose acetate butyrate, ¼-inch o.d. by 1/16-inch wall thickness and 5/16-inch o.d. by 1/16-inch wall thickness, red or blue in color. From 1947 to 1952, 976 piezometers using Tenite II tubing were installed in 18 dams. Tenite II tubing is not recommended because of its high coefficient of air absorption, increasing brittleness with age, and fatigue cracking caused by manufacturing impurities.
- Saran plastic tubing: polyvinyl chloride, 5/16-inch o.d. by 1/16-inch wall thickness, yellow in color. From 1941 to 1971, 1,007 piezometers using Saran tubing were installed in 20 dams. In addition to those disadvantages previously listed, Saran tubing is not recommended because of its increasing brittleness with age.
- Polyethylene plastic tubing: 5/16-inch o.d. by 1/16-inch wall thickness. From 1953 to 1958, 216 piezometers using polyethylene tubing were installed in 7 dams. This tubing has been found to be too soft and too easily cut.
- Polypropylene plastic tubing: 5/16-inch o.d. by 1/16-inch wall thickness. From 1965 to 1981, 195 piezometers using polypropylene tubing were installed in 3 dams. This tubing was the most recent tubing used on a hydraulic piezometer installation completed by the USBR. It is characterized by such desirable qualities as low air absorption, high bursting pressures, and a good range of working temperatures. Suggested specifications for polypropylene tubing are in Specification EDI-2 (app. A). Polypropylene or Nylon II tubing, consisting of a nylon inner tube and a polyethylene jacket, will be used for future installations.

(3) *Terminal Well Equipment.*—The equipment in the terminal wells consists of an air trap, water filter unit, plug shutoff valves, check valves, relief valves, blower fan unit, electric pump, hydraulic test pump, master gauge, separate gauges and brass pipe and fittings. Specifications for these items are in Specification EDI-3 (app. A).

(4) *Backfill Material.*—Typical backfill material consists of graded sand bentonite pellets, bentonite-sand mixtures, and selected fine materials. Specifications for backfill materials are in Specification EDI-4 (app. A).

(5) *Operating Valves.*—The operating valves[13] in the terminal well for the manifold and external circuits are listed below (fig. 2-11):

- Filler and bleeder valves on the air trap
- Inlet and outlet valves to the electric and hand pumps
- Inlet and outlet valves to the piezometer tips
- Manifold pressure valve[1] (No. 1)
- Inlet flushing valve[2] (No. 2)
- Manifold flushing valve (No. 3)
- Outlet flushing valve (No. 4)
- Manifold outlet valve (No. 5)
- Manifold inlet valve (No. 6)
- Safety valve on master gauge (No. 7)

(6) *Automatic Values.*—The automatic valves in the manifold system are listed below (see fig. 2-12):

(a) Bypass relief valve.—This valve is preset at the factory to approximately the maximum positive pressure that can be registered on the compound-hydrostatic-pressure Bourdon-tube gauges installed in the terminal well or to approximately the pressures likely (something less than maximum gauge pressures) during

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[13] Valve No. 1, should be used to throttle or control the pressure applied to the manifold system and external piezometer circuits. Valve No. 1 should be opened and closed slowly to prevent surges of pressure when circulating water in the system.

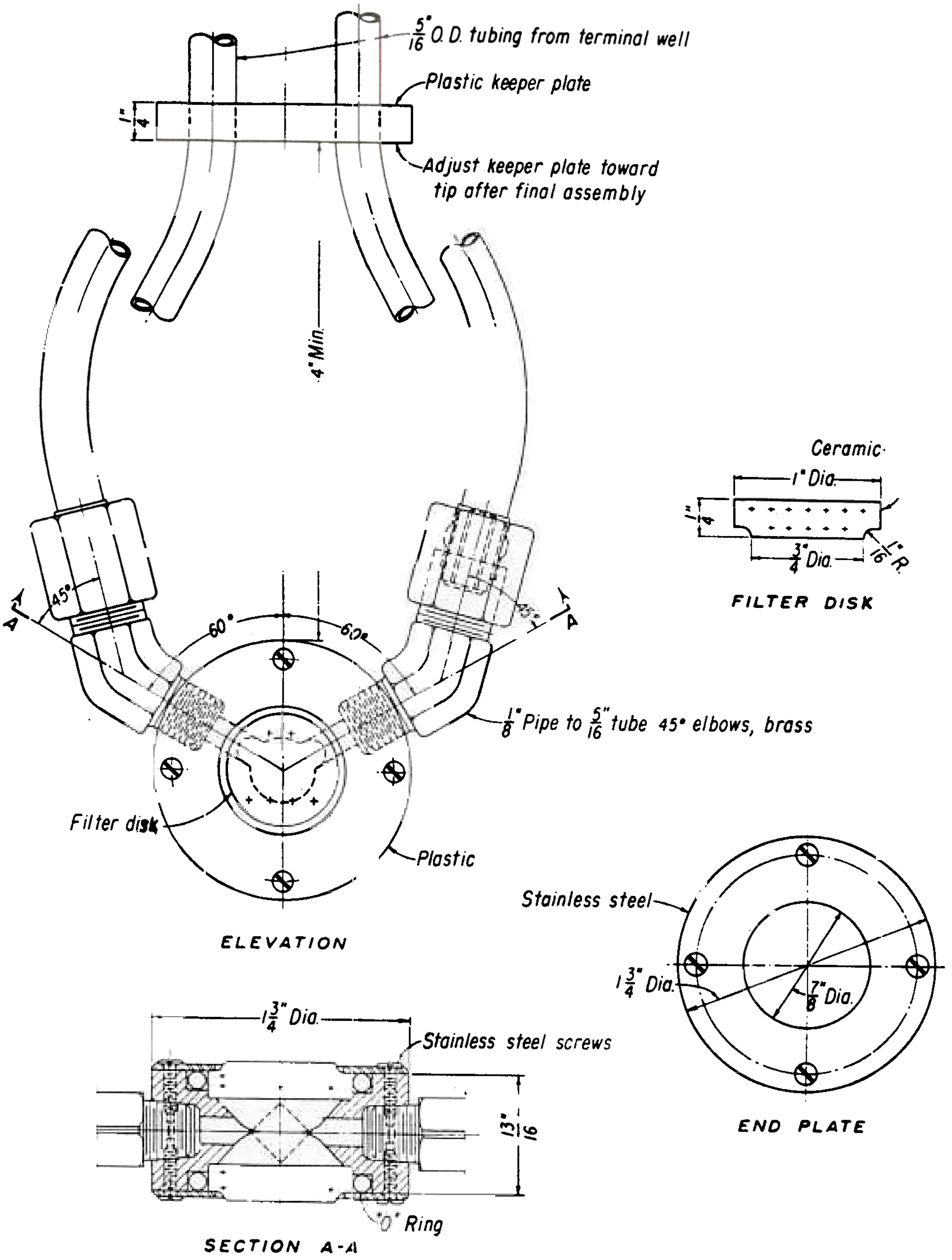

Figure 2-10.--Embankment twin-tube piezometer tip.

operation of the system. Thus, 200-foot gauges require a relief valve that will release to the bypass line at approximately 90 lb/in^2. Likewise, a 500-foot gauge requires a valve setting of 225 lb/in[14] or less. The relief valve prevents excess pumping pressure from being applied directly to the Bourdon-tube gauges. When this relief valve is first installed, sufficient pressure should be applied to open (crack) the valve to ensure its proper operation.

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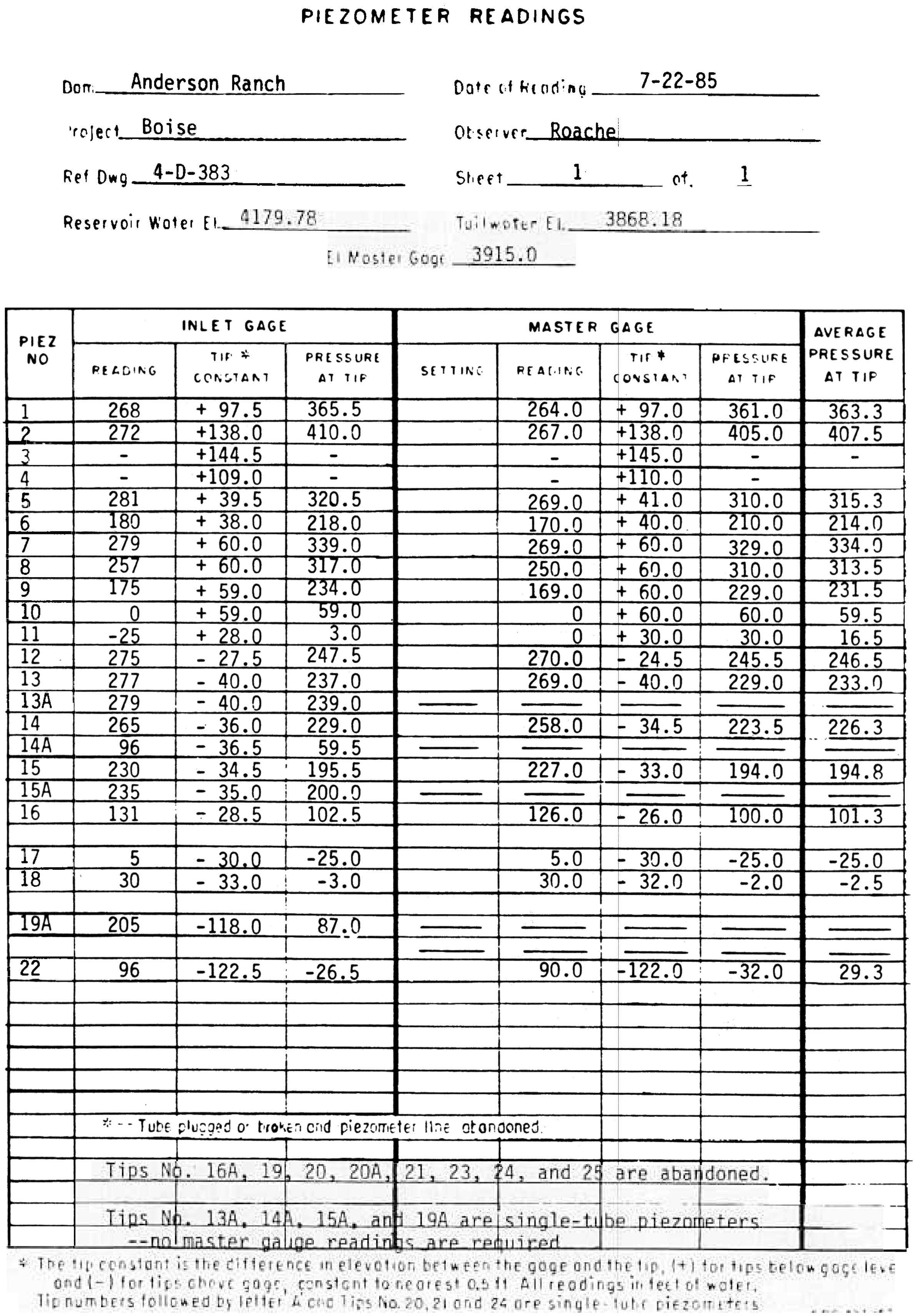
[14] Valves No. 2 through No. 7 are brass plug-type shutoff valves, which attach to ¼-inch standard brass pipe in the terminal well manifold system and replaced the angle-needle valves on the older installations.



PIEZOMETER READINGS

Dam Anderson Ranch
Date of Reading 7-22-85
Project Boise
Observer Roache
Ref Dwg 4-D-383
Sheet 1 of 1
Reservoir Water El. 4179.78
Tailwater El. 3868.18
El Master Gage 3915.0

PIEZ NO	INLET GAGE			MASTER GAGE				AVERAGE PRESSURE AT TIP
	READING	TIP * CONSTANT	PRESSURE AT TIP	SETTING	READING	TIP * CONSTANT	PRESSURE AT TIP	
1	268	+ 97.5	365.5		264.0	+ 97.0	361.0	363.3
2	272	+138.0	410.0		267.0	+138.0	405.0	407.5
3	-	+144.5	-		-	+145.0	-	-
4	-	+109.0	-		-	+110.0	-	
5	281	+ 39.5	320.5		269.0	+ 41.0	310.0	315.3
6	180	+ 38.0	218.0		170.0	+ 40.0	210.0	214.0
7	279	+ 60.0	339.0		269.0	+ 60.0	329.0	334.0
8	257	+ 60.0	317.0		250.0	+ 60.0	310.0	313.5
9	175	+ 59.0	234.0		169.0	+ 60.0	229.0	231.5
10	0	+ 59.0	59.0		0	+ 60.0	60.0	59.5
11	-25	+ 28.0	3.0		0	+ 30.0	30.0	16.5
12	275	- 27.5	247.5		270.0	- 24.5	245.5	246.5
13	277	- 40.0	237.0		269.0	- 40.0	229.0	233.0
13A	279	- 40.0	239.0	———	———	———	———	———
14	265	- 36.0	229.0		258.0	- 34.5	223.5	226.3
14A	96	- 36.5	59.5	———	———	———	———	———
15	230	- 34.5	195.5		227.0	- 33.0	194.0	194.8
15A	235	- 35.0	200.0	———	———	———	———	———
16	131	- 28.5	102.5		126.0	- 26.0	100.0	101.3
17	5	- 30.0	-25.0		5.0	- 30.0	-25.0	-25.0
18	30	- 33.0	-3.0		30.0	- 32.0	-2.0	-2.5
19A	205	-118.0	87.0	———	———	———	———	———
				———	———	———	———	———
22	96	-122.5	-26.5		90.0	-122.0	-32.0	29.3

* -- Tube plugged or broken and piezometer line abandoned.

Tips No. 16A, 19, 20, 20A, 21, 23, 24, and 25 are abandoned.

Tips No. 13A, 14A, 15A, and 19A are single-tube piezometers
--no master gauge readings are required

* The tip constant is the difference in elevation between the gage and the tip, (+) for tips below gage leve
and (-) for tips above gage, constant to nearest 0.5 ft. All readings in feet of water.
Tip numbers followed by letter A and Tips No. 20, 21 and 24 are single-tube piezometers

Figure 2-11.—Typical completed Form DC-438, Piezometer Readings. For terminal wells with one master gauge and one separate gauge.

(b) Check valve.—This valve is located between the pumps and the cartridge-type water filter. It prevents back pressure into the water filter and air trap when the bypass relief valve operates, which is particularly important when a plastic air trap is installed.

d. ***Monitoring Procedure.***—The procedure for taking periodic readings on the TTP involves little time and effort and requires only minimal training. The readings are taken on the individual (separate) 2½- or 3½-inch inlet and outlet pressure gauges for each piezometer and recorded in the appropriate columns of the data sheets. If the inlet and outlet gauge pressures agree within the desired limits (5 feet for 200-foot gauges and 10 feet for 500-foot gauges), obtain the arithmetical average and record the average gauge pressure. If the gauge readings do not agree within the desired limits, the procedures described in section f-(3) should be followed. Readings should be obtained to the nearest 1.0 foot on the 200-foot gauges, and to the nearest 2.0 feet on the 500-foot gauges.

All data for the hydraulic piezometers are taken in terminal wells at the downstream toe of the dam. Each terminal well contains a manifold system that measures the water pressure from the embankment or the foundation through the use of pressure gauges. The manifold system has three purposes: circulating water from the terminal well to the piezometer, thus removing all air and bacterial growth from the plastic tubes; allowing individual pressures to be recorded without disturbing the equilibrium pressure at the piezometer; and allowing a check reading to be taken once a year by the use of the master gauge, which compares the accuracy of the separate gauges. The master gauge reading procedure is covered in paragraphs e (2) and f (5) below.

Terminal wells that contain a master gauge and one separate gauge (this installation is only at Anderson Ranch Dam) or only one master gauge (not two separate gauges) (these installations are only at Fresno, Green Mountain, and Vallecito dams), or one master gauge and two separate gauges are read periodically using one of the following procedures for reading piezometers:

(1) *Reading Piezometers (Master Gauge and One Separate Gauge).*—

(a) Close all valves.

(b) Open the inlet and outlet valves to the hand pump and, in sequence, open the safety valve, outlet flushing valve, manifold flushing valve, manifold inlet valve, and pressure check valve. Pump and continue circulation until air bubbles no longer appear at the air trap. Close all valves except those on the pump.

(c) Open, in sequence, the safety valve, inlet flushing valve, manifold flushing valve, manifold outlet valve, and pressure check valve. Continue pumping to purge the air from the circuit, close all valves except those on the pump. Steps (b) and (c) have flushed the manifold.

(d) Record the gauge pressure (inlet gauge) for each piezometer tip on form DC–438 (see fig. 2-11). Add this reading to the tip constant and record.

(e) Open the inlet valve, the pressure check valve, and the safety valve for the master gauge. Place the same pressure on the master gauge as was read on the inlet gauge; this is the setting pressure.

(f) Open the outlet valve (from tip) and record the gauge pressure (master gauge) on form DC–438. Add the master gauge reading to the tip constant.

(g) Average the pressures at the tip for both the inlet and the master gauge and record on form DC–438.

(h) Repeat steps (e), (f), and (g) for each piezometer.

(2) *Reading Piezometers (Master Gauge Only).*—

(a) Close all valves (Nos. 1, 2, 3, 4, 5, 6, and 7). See figure 2-12.

(b) Open the manifold pressure valve (No. 1), the manifold inlet valve (No. 6), the manifold flushing valve (No. 3), and the manifold outlet valve (No. 5).

(c) Circulate the water by operating the pump until air bubbles no longer appear at the air trap. Replenish the water in the air trap as required to keep the air trap two-thirds to three-fourths full.

(d) Close the manifold outlet valve (No. 5) and open the safety valve (No. 7). Operate the pump until a pressure of about one-half the maximum reading of the gauge dial is reached, then close the manifold pressure valve (No. 1). This pressure should hold on the gauge; otherwise, leaks are present in the terminal well piping or valves. Such leaks must be repaired before accurate readings can be obtained.

(e) Set the gauge reasonably close to the expected reading (judging from previous readings) by additional pumping or by bleeding pressure through the discharge valve. For vacuum readings, set the gauge at zero. This is the inlet setting pressure.

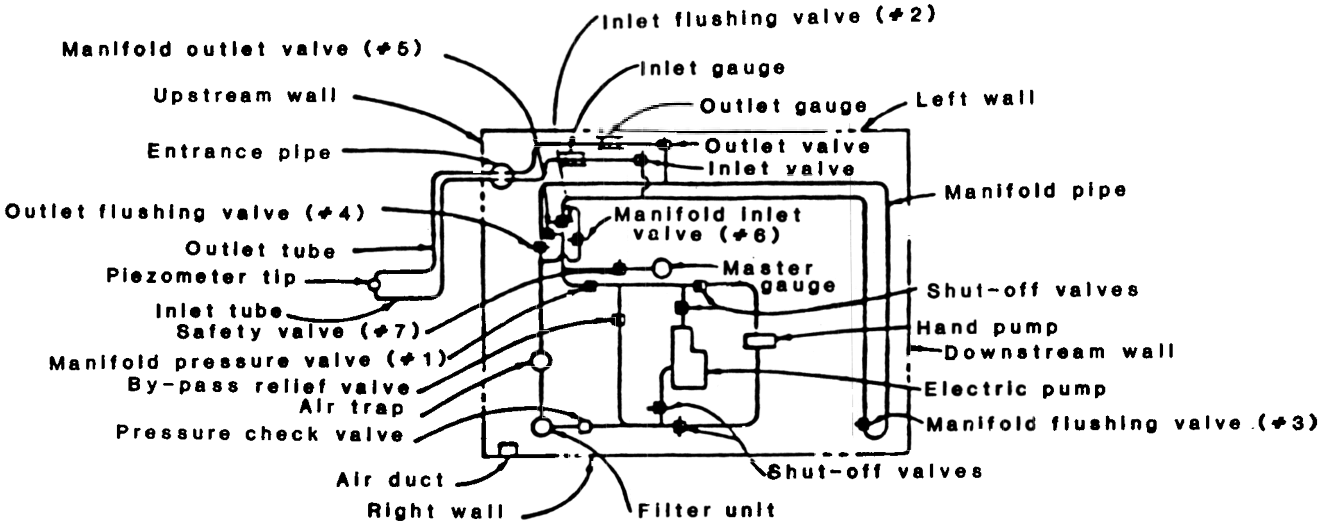


Figure 2-12.—Schematic of piping in terminal well. 101-D-502.

(f) With both manifold outlet and inlet valves for the piezometer closed and the manifold flushing valve (No. 3) open, crack an inlet valve to the piezometer to obtain a new gauge reading, then close the inlet needle valve. This reading is the inlet piezometer pressure.

(g) Reset the gauge reading close to that used in step (e) (the outlet setting pressure). Crack the outlet needle valve for the piezometer used in (f), then close the needle valve. This reading is the outlet piezometer pressure.

(h) Record the two gauge settings and the two gauge readings in steps (e), (f), and (g) to the nearest 0.5 foot in the appropriate columns of form 7–1347 (similar to the example shown for Sanford Dam, fig. 2-13).

(i) Repeat steps (e), (f), and (g) for the remaining piezometers.

(3) *Reading Piezometers (Master Gauge and Two Separate Gauges).* —

(a) Read the pressures on the individual (separate) dial gauges for each piezometer and record in the appropriate columns (inlet and outlet gauge readings) on form 7-1346 (fig. 2-14).

(b) If the inlet and outlet gauge pressures agree within the desired limits (5 feet for 200-foot gauges, and 10 feet for 50-foot gauges), determine the arithmetical average and record the average gauge pressure. Readings should be obtained to the nearest 1.0 foot on the 200-foot gauges, and to the nearest 2.0 feet on the 500-foot gauges.

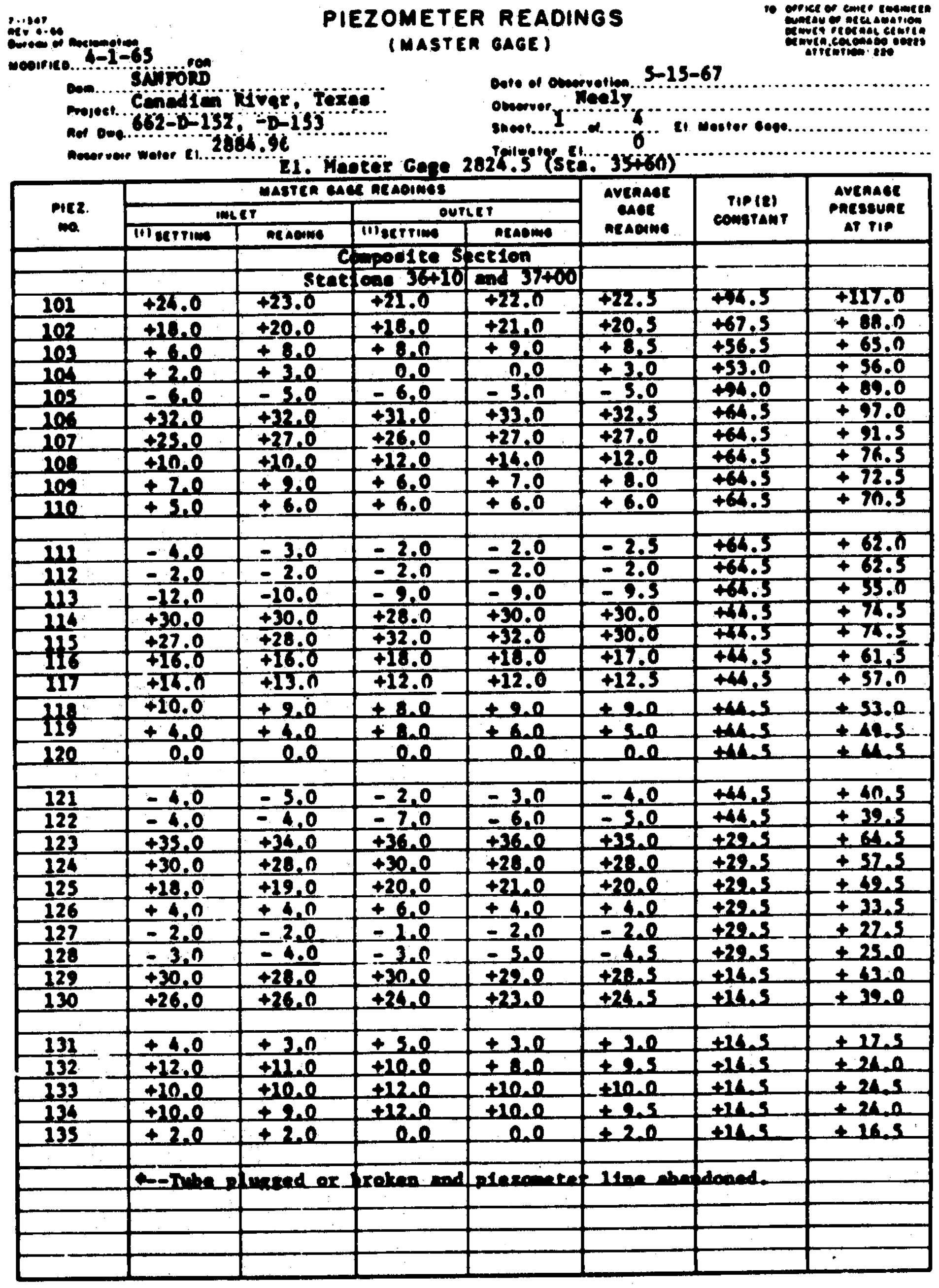
(c) Arithmetically add the average gauge pressure to the tip constant and record in the appropriate column on form 7-1346 (fig. 2-14).

(d) To obtain the annual master gauge readings see paragraph e(5).

e. ***Maintenance.***—The annual (or more often) maintenance required for hydraulic piezometers is accomplished within the terminal well. The maintenance tasks normally required are replacing lost water, deairing the manifold system, de-airing the piezometer tubing in the embankment, calibrating the separate gauges, and replacing inaccurate separate gauges. All these tasks should be accomplished when the annual master gauge readings are taken and require well-trained personnel.

The annual maintenance tasks for terminal wells should be accomplished using the following steps:

(1) Fill the water container (reservoir tank) in the terminal well with piezometer fluid consisting of distilled (or the best available) water to which 2 teaspoons of a 25-percent solution of QAC (Quaternary Ammonium Compound), a bacterial inhibitor and wetting agent used to stop the growth of algae and help remove air bubbles, has been added for each 10 gallons. During the recommended annual flushing of operating piezometer systems, 4 teaspoons of the 25-percent QAC solution should be added to the water reservoir within the terminal well for each 10 gallons of replacement water. Various QAC solutions, produced by Rohm and Hass Co., under the trade name Hyamine, and by Onyx Oil and Chemical Co., under the trade name BTC or Onyxide, can be used. For USBR installations, the QAC solution will be furnished on request by the Embankment Dam Instrumentation Section of the Structural Behavior Branch. Before performing the annual



7-1347
REV 4-66
Bureau of Reclamation
MODIFIED 4-1-65 FOR

PIEZOMETER READINGS
(MASTER GAGE)

TO OFFICE OF CHIEF ENGINEER
BUREAU OF RECLAMATION
DENVER FEDERAL CENTER
DENVER, COLORADO 80225
ATTENTION: 220

Dam SANFORD
Project Canadian River, Texas
Ref Dwg 662-D-152, -D-153
Reservoir Water El. 2884.96
Date of Observation 5-15-67
Observer Neely
Sheet 1 of 4 El Master Gage
Tailwater El. 0
El. Master Gage 2824.5 (Sta. 35+60)

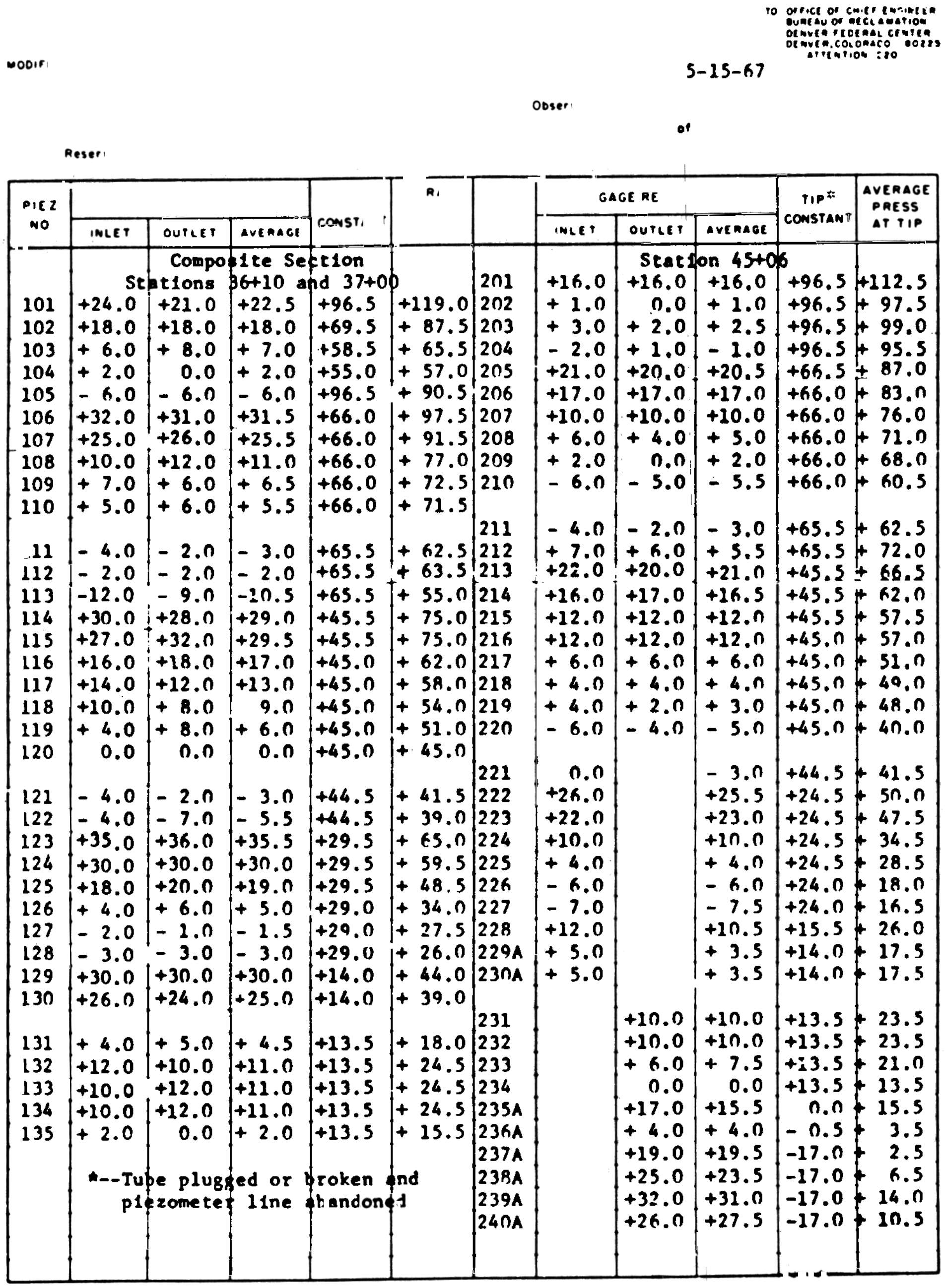
PIEZ. NO.	MASTER GAGE READINGS				AVERAGE GAGE READING	TIP (2) CONSTANT	AVERAGE PRESSURE AT TIP
	INLET		OUTLET				
	(1) SETTING	READING	(1) SETTING	READING			
		Composite Section					
		Stations 36+10 and 37+00					
101	+24.0	+23.0	+21.0	+22.0	+22.5	+94.5	+117.0
102	+18.0	+20.0	+18.0	+21.0	+20.5	+67.5	+ 88.0
103	+ 6.0	+ 8.0	+ 8.0	+ 9.0	+ 8.5	+56.5	+ 65.0
104	+ 2.0	+ 3.0	0.0	0.0	+ 3.0	+53.0	+ 56.0
105	- 6.0	- 5.0	- 6.0	- 5.0	- 5.0	+94.0	+ 89.0
106	+32.0	+32.0	+31.0	+33.0	+32.5	+64.5	+ 97.0
107	+25.0	+27.0	+26.0	+27.0	+27.0	+64.5	+ 91.5
108	+10.0	+10.0	+12.0	+14.0	+12.0	+64.5	+ 76.5
109	+ 7.0	+ 9.0	+ 6.0	+ 7.0	+ 8.0	+64.5	+ 72.5
110	+ 5.0	+ 6.0	+ 6.0	+ 6.0	+ 6.0	+64.5	+ 70.5
111	- 4.0	- 3.0	- 2.0	- 2.0	- 2.5	+64.5	+ 62.0
112	- 2.0	- 2.0	- 2.0	- 2.0	- 2.0	+64.5	+ 62.5
113	-12.0	-10.0	- 9.0	- 9.0	- 9.5	+64.5	+ 55.0
114	+30.0	+30.0	+28.0	+30.0	+30.0	+44.5	+ 74.5
115	+27.0	+28.0	+32.0	+32.0	+30.0	+44.5	+ 74.5
116	+16.0	+16.0	+18.0	+18.0	+17.0	+44.5	+ 61.5
117	+14.0	+13.0	+12.0	+12.0	+12.5	+44.5	+ 57.0
118	+10.0	+ 9.0	+ 8.0	+ 9.0	+ 9.0	+44.5	+ 53.0
119	+ 4.0	+ 4.0	+ 8.0	+ 6.0	+ 5.0	+44.5	+ 49.5
120	0.0	0.0	0.0	0.0	0.0	+44.5	+ 44.5
121	- 4.0	- 5.0	- 2.0	- 3.0	- 4.0	+44.5	+ 40.5
122	- 4.0	- 4.0	- 7.0	- 6.0	- 5.0	+44.5	+ 39.5
123	+35.0	+34.0	+36.0	+36.0	+35.0	+29.5	+ 64.5
124	+30.0	+28.0	+30.0	+28.0	+28.0	+29.5	+ 57.5
125	+18.0	+19.0	+20.0	+21.0	+20.0	+29.5	+ 49.5
126	+ 4.0	+ 4.0	+ 6.0	+ 4.0	+ 4.0	+29.5	+ 33.5
127	- 2.0	- 2.0	- 1.0	- 2.0	- 2.0	+29.5	+ 27.5
128	- 3.0	- 4.0	- 3.0	- 5.0	- 4.5	+29.5	+ 25.0
129	+30.0	+28.0	+30.0	+29.0	+28.5	+14.5	+ 43.0
130	+26.0	+26.0	+24.0	+23.0	+24.5	+14.5	+ 39.0
131	+ 4.0	+ 3.0	+ 5.0	+ 3.0	+ 3.0	+14.5	+ 17.5
132	+12.0	+11.0	+10.0	+ 8.0	+ 9.5	+14.5	+ 24.0
133	+10.0	+10.0	+12.0	+10.0	+10.0	+14.5	+ 24.5
134	+10.0	+ 9.0	+12.0	+10.0	+ 9.5	+14.5	+ 24.0
135	+ 2.0	+ 2.0	0.0	0.0	+ 2.0	+14.5	+ 16.5
	*--Tube plugged or broken and piezometer line abandoned.						

Figure 2-13.—Typical completed Form 7-1347, Piezometer Readings. For terminal wells with only one master gauge and terminal wells with two separate gauges. 101-D-509.

flushing of piezometers, inspect the cartridge in the water-filter unit and replace if necessary. Use no more of the QAC solution than the amount specified.

(2) Check the entire system in the terminal well to ensure that all valves are closed. Then open the filler valve and the bleeder valve to the air trap. Fill the air trap with piezometer fluid to within 3 inches of the top of the plastic air trap or to the top of the water level tubing on the steel air trap. Then close these valves.

(3) Fill the manifold system with piezometer fluid, subsequently flushing to remove air, and flushing the piezometer tips. For installations that contain only a master gauge or a master gauge and one separate



TO OFFICE OF CHIEF ENGINEER
BUREAU OF RECLAMATION
DENVER FEDERAL CENTER
DENVER, COLORADO 80225
ATTENTION 220

MODIF

5-15-67

Obser

of

Reser

PIEZ NO				CONST	R		GAGE RE			TIP* CONSTANT	AVERAGE PRESS AT TIP
	INLET	OUTLET	AVERAGE				INLET	OUTLET	AVERAGE		
	Composite Section						Station 45+06				
	Stations 36+10 and 37+00					201	+16.0	+16.0	+16.0	+96.5	+112.5
101	+24.0	+21.0	+22.5	+96.5	+119.0	202	+ 1.0	0.0	+ 1.0	+96.5	+ 97.5
102	+18.0	+18.0	+18.0	+69.5	+ 87.5	203	+ 3.0	+ 2.0	+ 2.5	+96.5	+ 99.0
103	+ 6.0	+ 8.0	+ 7.0	+58.5	+ 65.5	204	- 2.0	+ 1.0	- 1.0	+96.5	+ 95.5
104	+ 2.0	0.0	+ 2.0	+55.0	+ 57.0	205	+21.0	+20.0	+20.5	+66.5	+ 87.0
105	- 6.0	- 6.0	- 6.0	+96.5	+ 90.5	206	+17.0	+17.0	+17.0	+66.0	+ 83.0
106	+32.0	+31.0	+31.5	+66.0	+ 97.5	207	+10.0	+10.0	+10.0	+66.0	+ 76.0
107	+25.0	+26.0	+25.5	+66.0	+ 91.5	208	+ 6.0	+ 4.0	+ 5.0	+66.0	+ 71.0
108	+10.0	+12.0	+11.0	+66.0	+ 77.0	209	+ 2.0	0.0	+ 2.0	+66.0	+ 68.0
109	+ 7.0	+ 6.0	+ 6.5	+66.0	+ 72.5	210	- 6.0	- 5.0	- 5.5	+66.0	+ 60.5
110	+ 5.0	+ 6.0	+ 5.5	+66.0	+ 71.5						
						211	- 4.0	- 2.0	- 3.0	+65.5	+ 62.5
111	- 4.0	- 2.0	- 3.0	+65.5	+ 62.5	212	+ 7.0	+ 6.0	+ 5.5	+65.5	+ 72.0
112	- 2.0	- 2.0	- 2.0	+65.5	+ 63.5	213	+22.0	+20.0	+21.0	+45.5	+ 66.5
113	-12.0	- 9.0	-10.5	+65.5	+ 55.0	214	+16.0	+17.0	+16.5	+45.5	+ 62.0
114	+30.0	+28.0	+29.0	+45.5	+ 75.0	215	+12.0	+12.0	+12.0	+45.5	+ 57.5
115	+27.0	+32.0	+29.5	+45.5	+ 75.0	216	+12.0	+12.0	+12.0	+45.0	+ 57.0
116	+16.0	+18.0	+17.0	+45.0	+ 62.0	217	+ 6.0	+ 6.0	+ 6.0	+45.0	+ 51.0
117	+14.0	+12.0	+13.0	+45.0	+ 58.0	218	+ 4.0	+ 4.0	+ 4.0	+45.0	+ 49.0
118	+10.0	+ 8.0	9.0	+45.0	+ 54.0	219	+ 4.0	+ 2.0	+ 3.0	+45.0	+ 48.0
119	+ 4.0	+ 8.0	+ 6.0	+45.0	+ 51.0	220	- 6.0	- 4.0	- 5.0	+45.0	+ 40.0
120	0.0	0.0	0.0	+45.0	+ 45.0						
						221	0.0		- 3.0	+44.5	+ 41.5
121	- 4.0	- 2.0	- 3.0	+44.5	+ 41.5	222	+26.0		+25.5	+24.5	+ 50.0
122	- 4.0	- 7.0	- 5.5	+44.5	+ 39.0	223	+22.0		+23.0	+24.5	+ 47.5
123	+35.0	+36.0	+35.5	+29.5	+ 65.0	224	+10.0		+10.0	+24.5	+ 34.5
124	+30.0	+30.0	+30.0	+29.5	+ 59.5	225	+ 4.0		+ 4.0	+24.5	+ 28.5
125	+18.0	+20.0	+19.0	+29.5	+ 48.5	226	- 6.0		- 6.0	+24.0	+ 18.0
126	+ 4.0	+ 6.0	+ 5.0	+29.0	+ 34.0	227	- 7.0		- 7.5	+24.0	+ 16.5
127	- 2.0	- 1.0	- 1.5	+29.0	+ 27.5	228	+12.0		+10.5	+15.5	+ 26.0
128	- 3.0	- 3.0	- 3.0	+29.0	+ 26.0	229A	+ 5.0		+ 3.5	+14.0	+ 17.5
129	+30.0	+30.0	+30.0	+14.0	+ 44.0	230A	+ 5.0		+ 3.5	+14.0	+ 17.5
130	+26.0	+24.0	+25.0	+14.0	+ 39.0						
						231		+10.0	+10.0	+13.5	+ 23.5
131	+ 4.0	+ 5.0	+ 4.5	+13.5	+ 18.0	232		+10.0	+10.0	+13.5	+ 23.5
132	+12.0	+10.0	+11.0	+13.5	+ 24.5	233		+ 6.0	+ 7.5	+13.5	+ 21.0
133	+10.0	+12.0	+11.0	+13.5	+ 24.5	234		0.0	0.0	+13.5	+ 13.5
134	+10.0	+12.0	+11.0	+13.5	+ 24.5	235A		+17.0	+15.5	0.0	+ 15.5
135	+ 2.0	0.0	+ 2.0	+13.5	+ 15.5	236A		+ 4.0	+ 4.0	- 0.5	+ 3.5
						237A		+19.0	+19.5	-17.0	+ 2.5
	*--Tube plugged or broken and					238A		+25.0	+23.5	-17.0	+ 6.5
	piezometer line abandoned					239A		+32.0	+31.0	-17.0	+ 14.0
						240A		+26.0	+27.5	-17.0	+ 10.5

Figure 2-14.—Typical completed Form 7-1346, Piezometer Readings. For wells with separate gauges. 101-D-508.

gauge, the flushing of each piezometer is required on an annual basis (the master gauge reading is accomplished when each periodic reading is taken).

(a) *Flushing of Piezometers (Master Gauge and One Separate Gauge).—*

(1) Flush the manifold as described in section 30-d (1a through 1c).

(2) Open the pressure check valve, manifold inlet valve, outlet flushing valve, and slowly open the inlet and outlet valves for one piezometer and flush. Next, close the manifold inlet valve and the outlet flushing valve. This is direct flushing.

(3) Open the manifold outlet valve, and the inlet flushing valve and continue flushing. Then close all valves. This is reverse flushing. The flushing operations directed in (2) and (3) above should be continued until no air bubbles appear at the air trap. However, pumping should be continued for no more than 15 minutes on any piezometer circuit during a flushing operation. After flushing is completed on each piezometer circuit, close all valves in the terminal well, including the pump valves. The pressure check valve should be used to throttle or control the pressures applied during the flushing operations.

(b) *Flushing of Piezometers (Master Gauge Only).—*

(1) Flush the manifold as described in section 30-d (2a through 2d).

(2) Open valves No. 1, 6, and 4. See figure 2-3. Slowly open the inlet and outlet valves for one piezometer and flush. Next, close valves 6 and 4. This is direct flushing.

(3) Open valves No. 5 and 2 and continue flushing. Then close all valves. This is reverse flushing.

The flushing operations directed in (2) and (3) above should be continued until no air bubbles appear at the air trap. However, pumping should be continued for no more than 15 minutes on any piezometer circuit during a flushing operation. After flushing is completed on each piezometer circuit, close all valves in the terminal well, including the pump valves. Valve No. 1 should be used to throttle or control the pressures applied during the flushing operations.

(c) *Flushing of Piezometers (Master Gauge and Two Separate Gauges).*—There have been three different types of terminal wells constructed by the USBR using this type of installation. The wells differ only according to the numbering of the different valves. In the following paragraphs, if the name of the valve is inserted in place of its number (see sect. 30, e5), any terminal well can be properly flushed.

(1) Open the inlet and outlet valves to the electric or hand pump (whichever is used) and, in sequence, open valves No. 7, 2, 3, 4, and 1. Start pumping and continue circulation until air bubbles no longer appear at the air trap. In the same sequence, close all valves except those on the pump.

(2) Open, in sequence, valves No. 7, 5, 3, 6, and 1 and flush. Continue pumping to purge the air from the circuit, and in the same sequence, close all valves except those on the pump.

(3) Open, in sequence, valves No. 7, 2, 6, and 1 and flush. Continue pumping to purge the air from the circuit, and in the same sequence, close all valves previously opened (valve No. 3 remains closed).

(4) Add fluid to the air trap when the water level shows it is less than half full.

(4) Extend filling and flushing to the piezometer tips. To do so, proceed as follows:

(a) Open valves No. 1, 2, and 4. Then, slowly open the inlet and outlet valves for one piezometer and flush. Next, close valves No. 2 and 4. This is direct flushing.

(b) Open valves No. 5 and 6 and continue flushing. Then close all valves. This is reverse flushing.

The flushing operations directed in paragraphs (4)(a) and (4)(b) should be continued until no air bubbles appear at the air trap. However, pumping should be continued for no more than 15 minutes on any piezometer circuit during a flushing operation. After flushing is completed, close all valves in the terminal well, including the pump valves.

Valve No. 1 should be used to throttle, or control, the pressure applied during the flushing operation. Pumping pressures should be limited to approximately 30 feet of gauge pressure greater than the pressure observed for a piezometer tip. For example, if a piezometer tip is reading 100 feet of water, pumping pressures should be limited to 130 feet of gauge pressure.

Piezometer circuits should be flushed 2 to 7 days before regular readings or master gauge readings are obtained.

Both direct and reverse flushing should be performed on external piezometer circuits as described in paragraphs (4)(a) and (4)(b) above to complete the flushing on each tip. After flushing has been completed, check the residual pressures on the pair of gauges (2½- or 3½-inch) for each piezometer. If pressures differ by more than 5 feet on 200-foot gauges or by more than 10 feet on 500-foot gauges, repeat flushing of the lines. For operating piezometers, throttle (partially close) valve No. 4 or No. 6, i.e., the valves on the return line into the air trap (depending on the direction of flushing), so that a zero pressure or a vacuum does not develop on the return line.

(5) Master gauge (6-inch dial) reading: (Maintenance flushing must be accomplished before a master gauge reading is taken).

(a) Follow the procedures for flushing the manifold and piezometer as described in paragraphs (3) and (4) above. After at least 2 days (preferably 7 days), read the gauge pressures on the pair of separate gauges for a piezometer and record them on form 7–1346 (fig. 2-14). These readings will be used for the setting pressures.

(b) Open the pump valves and then start pumping. Open, in sequence, valves No. 1, 2, 6, and 7. Throttle valve No. 1 and slowly close valve No. 6 to set the inlet pressure recorded on form 7–1346 (from the small gauge) on the master gauge. After setting the inlet balancing pressure, close all valves except No. 2 and No. 7 and stop pumping. Record the inlet setting pressure on form 7–1347 (fig. 2-13) and crack the desired inlet valve (to the tip) for a piezometer. Read and record the corresponding pressure observed on the master gauge. Then close the inlet valve (to the tip). The balancing pressure must be set on the master gauge before a reading is taken; otherwise, the equilibrium at the piezometer tip will be lost and the reading will not be accurate.

(c) To obtain the outlet master gauge reading, first resume pumping, then open, in sequence, valves No. 1, 5, 4, and 7. Throttle valve No. 1 as before and slowly close valve No. 4 to obtain the outlet setting pressure (from the small gauge) on the master gauge. Then close all valves except No. 7 and No. 5 and stop pumping. Record the outlet setting pressure, then crack the desired outlet valve (from the tip) for a piezometer. Read and record the responding pressure observed on the master gauge, using the appropriate column on form 7–1347. Then close the outlet valve (to the tip).

(d) To obtain the average gauge reading on form 7–1347, average the inlet and outlet readings (not the setting pressures). Record this value in the appropriate column on the form. Add this value to the master gauge tip constant for the piezometer (the difference in elevation between the master gauge and the corresponding piezometer tip) and record as the average pressure at the tip.

(e) When the small gauges indicate a negative pressure for a tip, close the inlet valve on the hand pump, open valves No. 1 and 7 and valve No. 2 or 5 (depending on the desired access line to the tip) and apply a suction stroke on the hand pump. Then close valve No. 1. Record the master gauge reading on form 7–1347 as the setting pressure.

(f) Crack the desired inlet or outlet valve (to or from the tip) for the desired piezometer on which negative readings are indicated. Record the responding reading on the master gauge and close all valves.

(g) Repeat as in paragraphs 5(e) and (f) above, for the opposite valve (inlet or outlet) and record the responding negative reading on the master gauge. Close all valves.

f. *Data Processing.*—Pressure readings from each TTP are recorded on form 7–1346, as shown on figure 2-13. These data are transmitted by mail or by computer to the Structural Behavior Branch. Upon arrival, the data should be processed, reviewed, and reported as discussed in section 25. An example plot of TTP data is shown on figure 2-15.

31. Pneumatic Piezometers.—a. *Usage.*—Pneumatic piezometers are installed in both foundation and embankment material. They may be used where construction operations could damage other types of instrumentation, such as standpipe installations within an embankment. Their usage also minimizes interference with construction equipment.

b. *Advantages and Limitations.*—Pneumatic piezometers have several advantages: easy maintenance, a relatively short lag time in reading, the level of the tubes and readout terminal are independent of the level of the piezometer tips, and no freezing or other water-related maintenance problems are likely. The only maintenance required is the occasional calibration of the gauges and the removal of water from the lines as needed.

The only significant limitations to the use of pneumatic piezometers are that they have been used for a relatively short time and their long-term durability has yet to be fully proven. One long-term durability problem that has not been overcome is the cold weather that causes the breaking of tubing during construction. There is also a significant amount of time required in obtaining the readings. In installations with long tubing lengths (over 500 feet), personnel must be very diligent and attentive in taking time-consuming readings. This reading process creates the need for considerable training of personnel. The readings must be reduced by mathematical calculation and cannot be used directly as with a standpipe piezometer.

Tests on pneumatic piezometers have indicated that they should be calibrated before installation with the required tube lengths attached so that the offset from zero can be measured. If this offset is great, it should be used in reducing all data taken by the instrument. In addition, when using pneumatic piezometers, a diaphragm displacement of no more than 0.01 cm^3 or less should be required when purchasing the piezometers. Diaphragm displacements larger than 0.01 cm^3 can cause an increase in pore water pressure and give erratic data.

c. *Description of Equipment.*—Pneumatic piezometers use gas pressure to measure fluid water pressure. The water pressure passes through a porous filter and pushes against a diaphragm; this causes the diaphragm

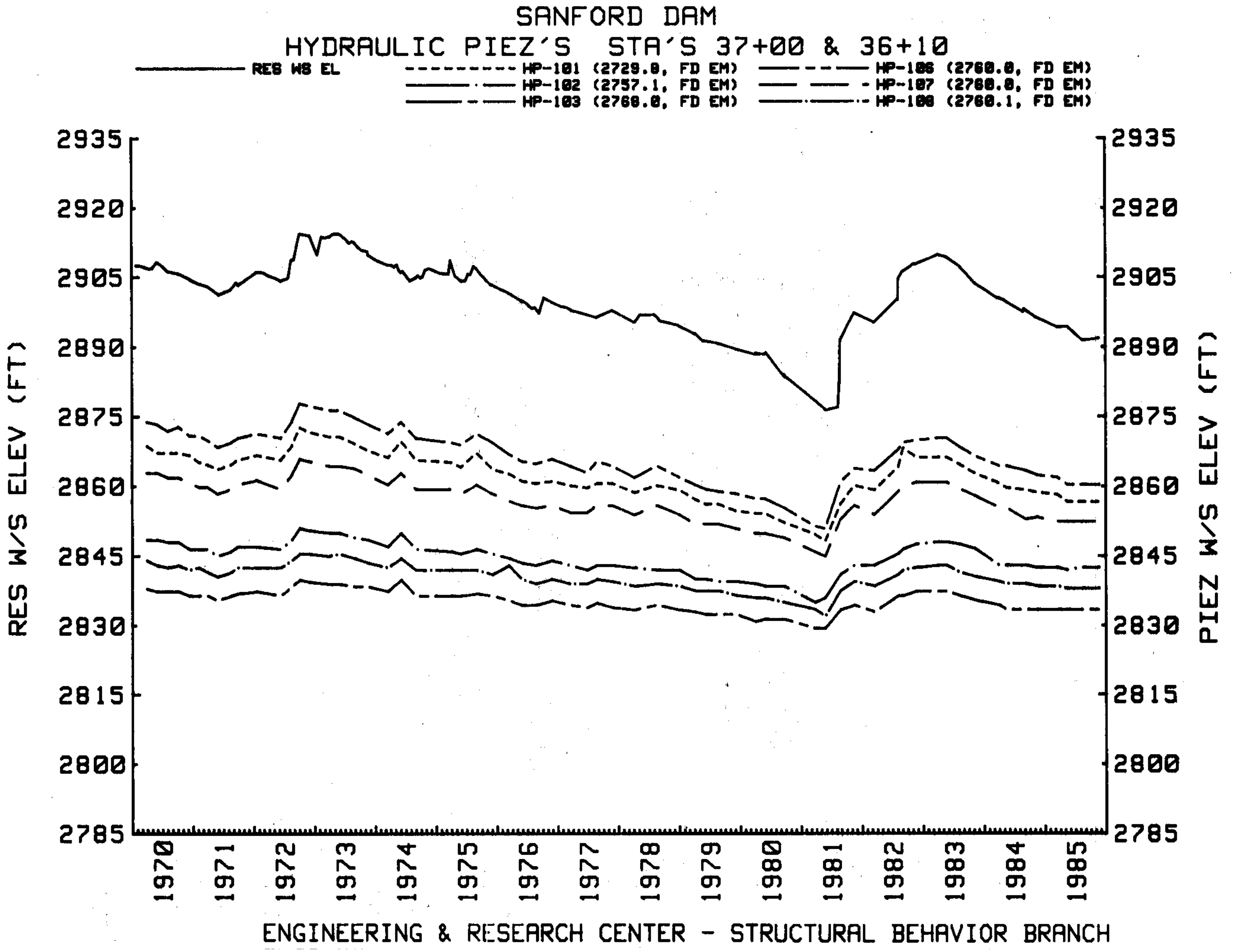


Figure 2-15.—Example plot of twin-tube piezometer data.

to warp and close a tube. Pneumatic pressure is then applied against the diaphragm through a tube attached to the piezometers at one end and to a manifold-readout unit at the other end. The pneumatic pressure needed to force the diaphragm back to its original position is measured. All excess pressure is released to the atmosphere through the vent line.

Pneumatic piezometers consist of a pneumatic piezometer tip assembly, tubing bundle, tubing bundle terminal assembly, portable pneumatic-pressure indicator, pneumatic terminal panel, pneumatic terminal pipes, riser pipes, and backfill material.

(1) *Piezometer Tip Assembly.*—The tip assembly basically consists of a pressure transducer covered with a porous stone disk. Pore-water pressure enters the device through the porous stone and presses against the transducer diaphragm. Pneumatic pressure is then used to return the transducer diaphragm to its original position. That amount of pressure is equal to the pore pressure at the tip. Figure 2-16 illustrates the design of a pneumatic piezometer tip assembly. Specifications for acceptable pneumatic piezometer tip assemblies are given in Specification EDI-5 (app. A).

(2) *Tubing Bundles.*—Tubing bundles leading from the piezometer tip to the tubing bundle terminal assembly must be as specified in Specification EDI-6 (app. A).

(3) *Tubing Bundle Terminal Assembly.*—A tubing bundle terminal assembly allows proper reading of the piezometers. Specifications for this assembly are in Specification EDI-7 (app. A).

(4) *Portable Pneumatic Pressure Indicator.*—This self-contained unit (fig. 2-17) is used to determine pressure readings on the various piezometers. Specifications for the unit are given in Specification EDI-8 (app. A).

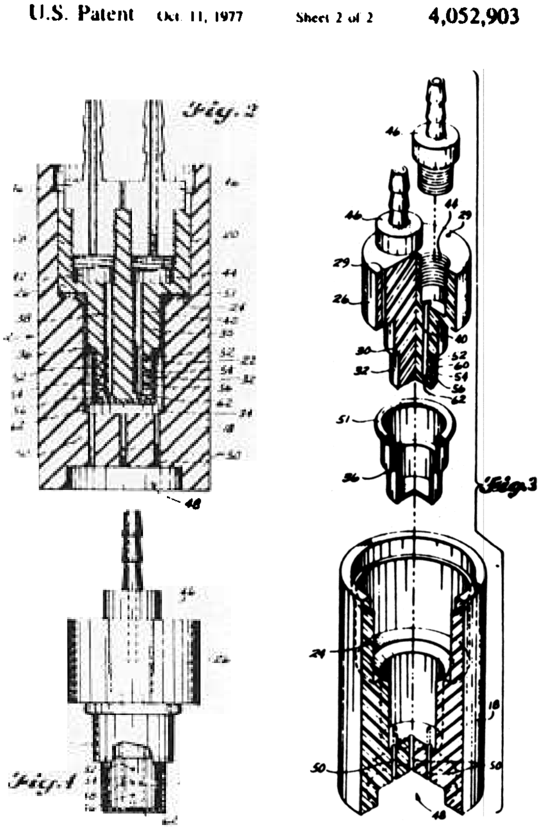


Figure 2-16.—Pneumatic piezometer tip assembly.

(5) *Terminal Panel.*—The pneumatic terminal panel is where the piezometer pressures are read. It is basically a metal-enclosed stationary system containing two switching manifolds and one vent manifold securely anchored to the instrument house wall. Figure 2-18 is a photograph of the unit, and Specification EDI–9 (app. A) describes its requirements.

(6) *Terminal Pipes.*—These terminal pipes, which may be used instead of the terminal panel, allow at least 20 pneumatic instruments to be terminated at each pipe and provide for organized readout. The pipe should be arranged as shown on figure 2-19. Specification EDI-10 (app. A) covers the unit's material requirement.

(7) *Riser Pipes, Plugs, and Other Materials.*—Specifications for riser pipes, pipe plugs, and line fittings are in Specification EDI–11 (app. A).

(8) *Backfill Material.*—Typical backfill material consists of graded sand, bentonite pellets, bentonite-sand mixtures, and selected fine materials. Backfill material specifications are in Specification EDI-4 (app. A).

d. ***Installation.***—(1) *Piezometer Installation.*—Pneumatic piezometers are installed in drill holes in a manner similar to that described in section 32-e. A typical embankment installation is illustrated on figure 2-20.

During construction, the embankment should be carried above the proposed piezometer locations. Trenches should then be excavated in the embankment for the instrument tubing, and offset trenches (fig. 2-20) are excavated from the main trench for instrument installations. These offset trenches should be excavated at right angles to the main trench and at the same bottom elevation. All trench excavation should be completed before any drilling in the offset areas for instrument installation (see fig. 2-21).

Seepage cutoffs should be installed along the trenches for two conditions: (1) when zones of different materials are encountered in the trenches, seepage cutoffs should be excavated at the contact of the zones, at least 2 feet into each zone longitudinally along the trench; and (2) in homogeneous embankment material at 50-foot intervals or between successive piezometers along the trench, whichever results in the shortest spacing. These cutoffs and those for zone 1 material should extend at least 1 foot along the trench line. In

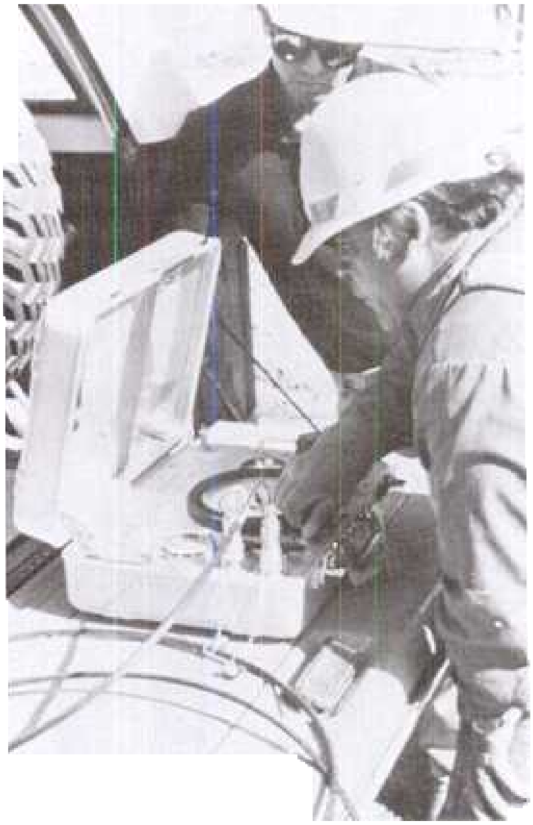


Figure 2-17.—Portable pneumatic pressure indicator. P801-D-81005.

each case, the excavation for the cutoff must extend outward at least 0.5 feet from the sides and bottom of the trench.

For drill hole installation, burlap or cloth bags 3.5 inches in diameter and 7 inches long (with a drawstring) should be placed around and attached to the piezometer. A 60-micron porous tube should be used. The bags should be filled with clean-graded sand (standard Ottawa sand may be used) having approximately the gradation of well sand, and kept saturated.

Embankment piezometers may have a ceramic filter added so that pore-water pressures can be measured accurately. Piezometers installed in offset trenches must be placed on at least 3 inches of the zone material through which the trench is passing. The 3-inch layer should be compacted carefully to the density of the surrounding material. However, material placed over the piezometer tip must not be mechanically compacted until a 9-inch-thick layer of the same zone material has been placed over the piezometer. Instrumented drill holes and offset trenches should be backfilled as indicated on figure 2-20.

(2) *Tubing Installation.*—The tubing bundles are placed in layers in the trenches. All piezometers are tested to determine whether they are functioning properly before installation. They must also be checked after installation, but before any layer of tube bundles is covered.

Backfill material consisting of bentonite and concrete-sand material should be placed dry on the bottom of the trenches and compacted to a minimum depth of 3 inches. A layer of loose tube bundles should then be laid along the trenches. (No tension should be applied to the tubing.) After the equipment is tested, the tubes should be covered with a layer of bentonite and concrete-sand mixture (one part bentonite to three parts concrete sand measured by dry weight) compacted to a minimum depth of 3 inches. Individual tubes should be separated by a minimum of 1.5 inches, as shown on figure 2-22. The cover material should be carefully compacted to the density required for the surrounding embankment. The method of compaction must be approved before the compaction process is begun.

Succeeding layers of tube bundles should be covered by 3 inches of compacted bentonite and concrete-sand material; except for the top layer of tube bundles in the trenches, which should be covered by two 3-inch-thick compacted layers. The remainder of the trench, above the tube bundles and their cover, should be

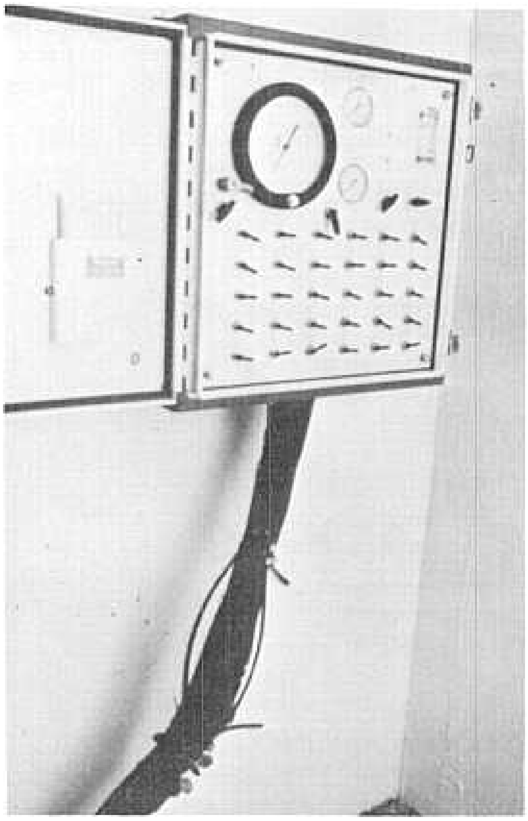


Figure 2-18.—Pneumatic terminal panel.
P801-D-81006.

backfilled with the same material as that adjacent to the trench, and it should be compacted to the density required for the surrounding embankment.

Backfill material for the seepage cutoff trenches consists of the same 1:3 mixture of bentonite and concrete sand used to cover the tubing. These cutoffs must be installed, as previously discussed in section 31-d, where zone contacts are crossed, between each piezometer in zone 1 material, and on 50-foot centers along all main trenches. The cutoff trench backfill material must be at least 1 foot wide at these locations. It should be compacted to the same density as the tubing cover and carried to the top of the trench as backfilling around the tubing progresses.

When pneumatic instrumentation is installed at various levels in the embankment, the tubing from the instruments must be encased in a riser pipe (see fig. 2-23). These risers should be advanced with embankment placement by adding sections of the riser pipe as embankment placement operations progress. Backfill material consisting of a 1:3 bentonite and concrete-sand mix should be placed and compacted inside the riser pipe and around the tubing. The entire riser section should then be filled around the tubing as the pipe is advanced. On the outside of the riser pipe, a 3-foot diameter area of specially compacted material should be placed. The transition of the tube bundles from horizontal layers in the trenches to vertical risers should be made with a 12-inch minimum radius bend. No tension is allowed on the tubing in this transition.

e. ***Monitoring Procedures***—Pneumatic piezometers are read at the manifold-readout (pneumatic terminal) panel or at a terminal pipe using a portable readout unit. Pressure is transmitted by compressed nitrogen gas through the tube bundle to the piezometer tip. The gas pressure equalizes the water pressure against a rubber diaphragm in the piezometer tip. When the equalization occurs, excess gas pressure is vented to the atmosphere.

Each piezometer requires a constant flow of gas. An initial supply pressure setting of 140 lb/in^2 is recommended to allow an adequate flow rate. Once an initial output pressure gauge reading is established for a given piezometer, a supply pressure reading of 30 to 40 lb/in^2 above the output gauge reading may be used to conserve the gas supply. For example, an initial output pressure gauge reading of 30 lb/in^2 means that the input pressure for future readings need only be 60 to 70 lb/in^2. Gas supply conservation is directly affected

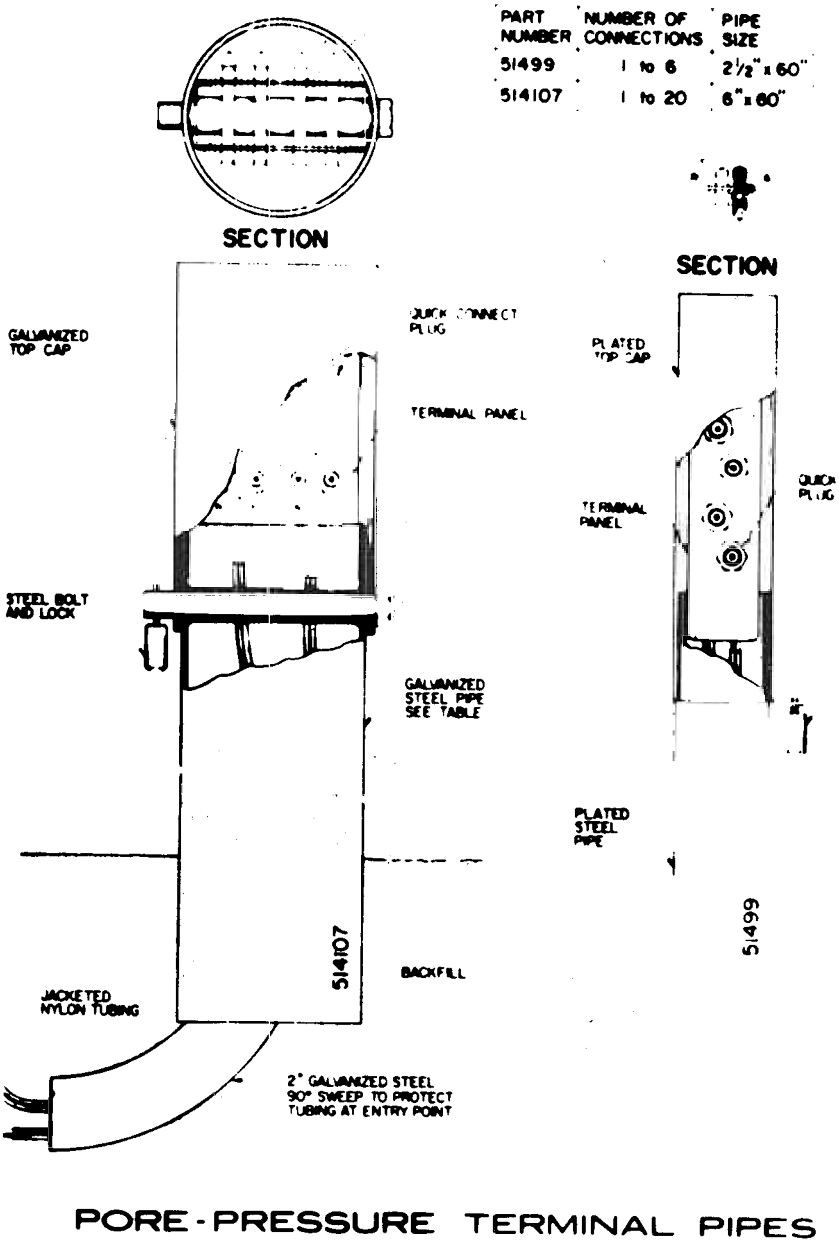


Figure 2-19.—Pneumatic terminal pipes.

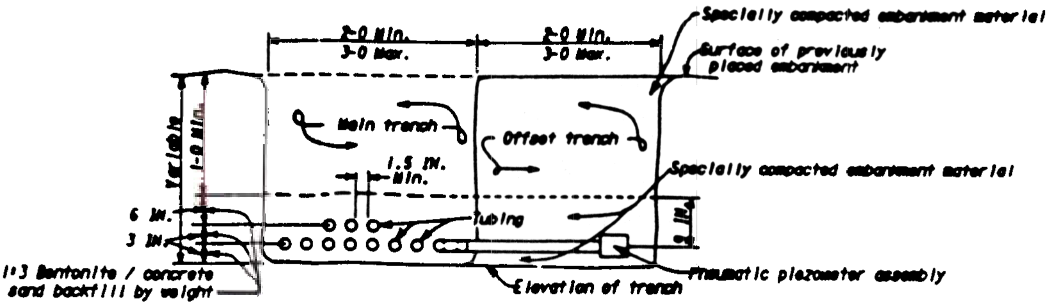
by the volume flowing through the flowmeter. Immediately after a reading is completed, another reading should be taken for verification; then the flow should be shut down. An accurate pressure reading occurs only at a low flow or null balance position; at high flow, the pressure has been changed somewhat by the flow.

The step-by-step procedure for reading pressure cells using the manifold-readout (pneumatic terminal) panel equipment is as follows:

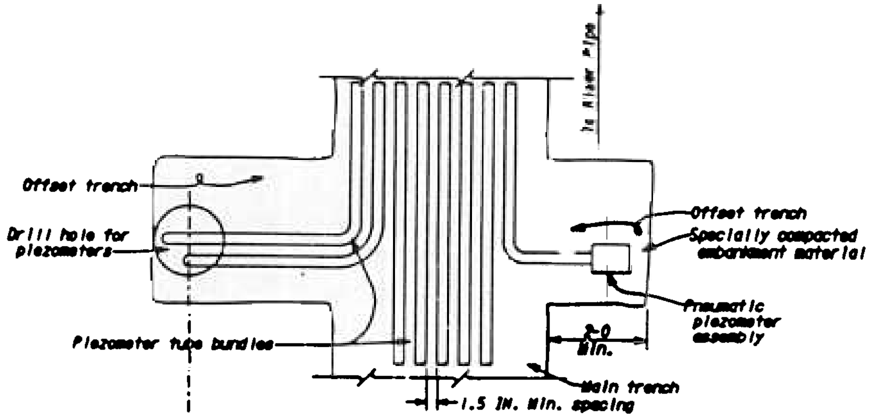
(1) Check the zero setting on the output pressure gauge, then close all valves on the pneumatic-pressure panel.

(2) Open the vent valve and adjust the supply pressure to 140 lb/in^2 or to 30 to 40 lb/in^2 above the previous reading for the piezometer to be monitored.

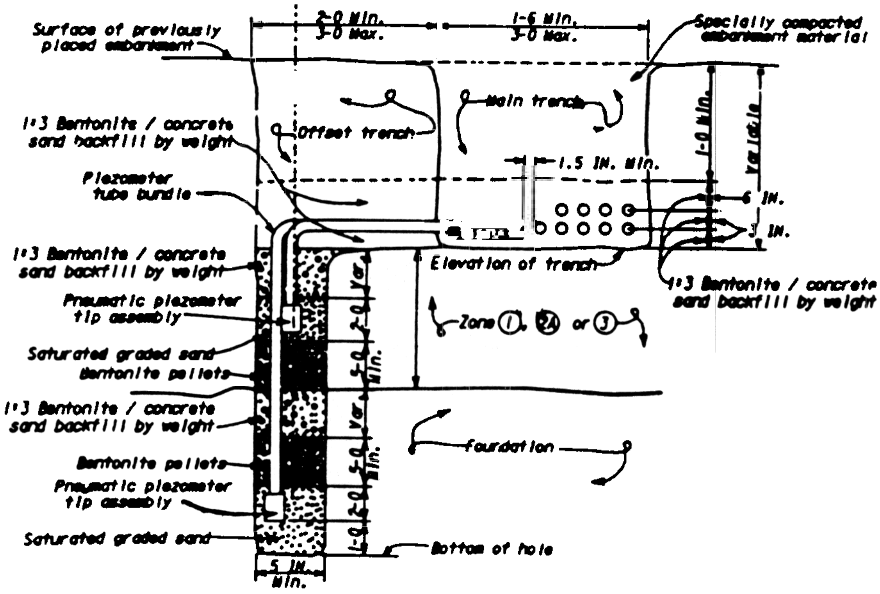
(3) Adjust the metered input valve so that the flowmeter indicates a flow rate of 0.1 SCFH (standard cubic feet per hour) with the input vent open. (The device was initially calibrated at that flow rate.) The flow



PNEUMATIC PIEZOMETERS
TYPICAL EMBANKMENT INSTALLATION
NO SCALE



OFFSET TRENCH PLAN
NO SCALE



PNEUMATIC PIEZOMETERS
TYPICAL FOUNDATION INSTALLATION
NO SCALE

Figure 2-20.—Pneumatic piezometer embankment and foundation installation.

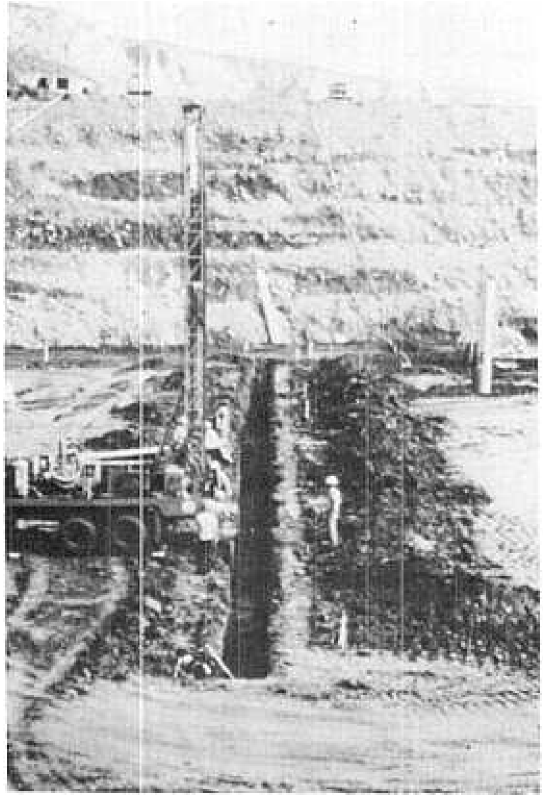


Figure 2-21.—Trench excavation in embankment for installation of piezometer instrumentation. P801-D-81007.

for the initial reading on the piezometer can be at a higher flow rate to fill and pressurize the pneumatic tubes. Once the tubes are filled, the flow rate should be reduced to 0.1 SCFH.

(4) Open the transfer valve to connect the input circuitry to the output pressure gauge.

(5) Close the vent valve and read the pressure increase on the output pressure gauge.

(6) Wait for the output pressure gauge to stabilize, gently tap the gauge to ensure that the pointer is moving freely and record the pressure reading.

(7) Verify the reading by opening the vent valve until the pointer on the output pressure gauge starts to fall, then close the vent valve so that the flow rate can repressurize the piezometer.

(8) Recheck the pressure measurement reading indicated on the output pressure gauge after the pointer stops.

(9) The system may be shut down after reading by closing the supply pressure regulator, opening the vent and transfer valves to bring the output pressure gauge to zero, then closing all valves except the metering valves.

f. ***Data Processing.***—The pressures are read in pounds per square inch. They should then be converted to piezometric elevations by multiplying the readings by a factor of 2.31 to obtain the pressure in feet of water, then adding this value to the tip elevation. Figure 2-24 shows a sample data sheet.

The data are transmitted by mail or by computer to the Structural Behavior Branch for analysis. Upon arrival, the data are processed, reviewed, and reported as directed in section 25. An example plot of pneumatic piezometer data is shown on figure 2-25.

32. Vibrating-Wire Piezometers.—a. ***Usage.***—VWP's (vibrating-wire piezometers) are installed in both foundation and embankment materials to monitor piezometric and ground-water levels. Like other closed system piezometers, VWP's are used in embankments where standpipe piezometers could be damaged by or interfere with construction equipment. In some installations, VWP's have been used to check the accuracy of adjacent instruments. They are also used where negative pore pressures need monitoring.

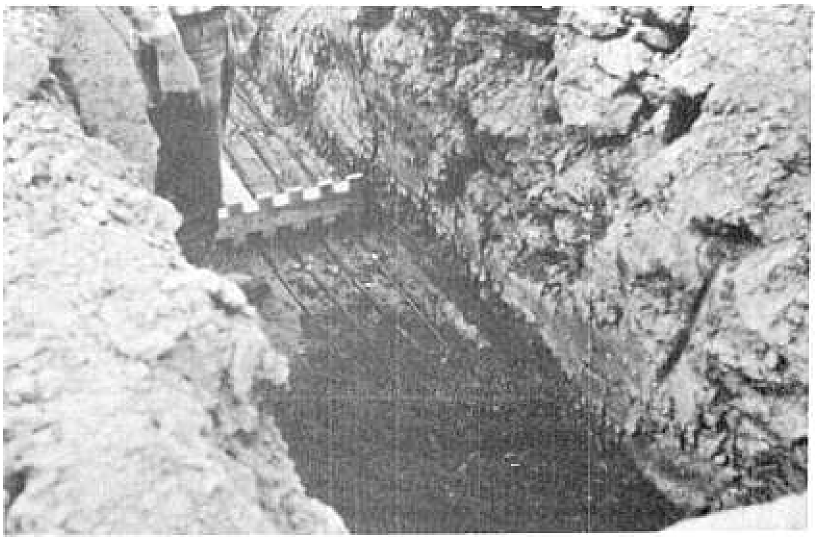


Figure 2-22.—Installation of piezometer tubing in trench. P801-D-81008.

b. ***Advantages and Limitations.***—The advantages of vibrating-wire piezometers include easy readout and maintenance, a short response time in reading, and the ability to read negative pore pressures. In addition, the level of the cables and the readout device are independent of the level of the piezometers; a central observation system may be used at a reasonable cost; and no freezing or other water-related maintenance problems occur. Long permissible electrical leads normally allow the use of existing structures for terminal facilities, thereby significantly decreasing the total cost of the system. The only maintenance required is the care and maintenance of the readout unit and the batteries.

The limitations of VWP's include the inability to de-air the tip. This renders long-term measurements of negative pore pressures in partially saturated soils and measurements in gaseous organic soils somewhat questionable. In applications where very small pressure variations are significant, corrections must be made for changes in barometric pressure and temperature, although this is not usually a problem on most dams. The piezometers, if installed in a drill hole, will measure any remaining or induced drill water, thus causing artificial readings until totally dissipated.

Some specialized training for personnel is required for calibrating and testing the equipment before installation. In fact, tests on vibrating-wire piezometers have indicated that they should be recalibrated before installation to check the calibration factor supplied by the manufacturer. This calibration will cause extra work for the installation crew, but it will provide confidence in future data. The readings themselves are simple to take after installation, although they must be reduced by a mathematical calculation and cannot be used directly as those for a standpipe piezometer. Vibrating-wire piezometers have now been used at several facilities and are planned for use at many more. Although the USBR does not have the length of experience with vibrating-wire piezometers that it has with hydraulic piezometers, the VWP's appear to be rugged and durable enough to perform accurately for many years. The ease with which vibrating-wire piezometers can be automated may become an increasingly important advantage in the future.

c. ***Description of Equipment.***—The piezometer tip contains a porous disk that allows water pressure to enter and press against a stainless steel diaphragm. A high-strength steel wire is fixed to the center of the diaphragm at one end and to an "end block" at the other end. This wire is hermetically sealed within a stainless steel member and set to a predetermined tension during manufacture. Pressure applied to the diaphragm causes it to deflect, thereby changing the tension and resonant frequency of the wire. A coil/magnet assembly is used with a readout device to "pluck," or vibrate, the wire and to measure the wire's vibration frequency. Either calibration charts or an equation, with a simple gauge factor, enables the user to calibrate pore pressure from the readings.

The vibrating-wire piezometer system consist of a piezometer tip, electrical cable, readout unit, and backfill materials.

(1) *Piezometer Tip Assembly.*—As previously described, the piezometer tip assembly consists of a stainless steel body, porous disk, high-strength steel wire, stainless steel diaphragm, transducer for transmitting

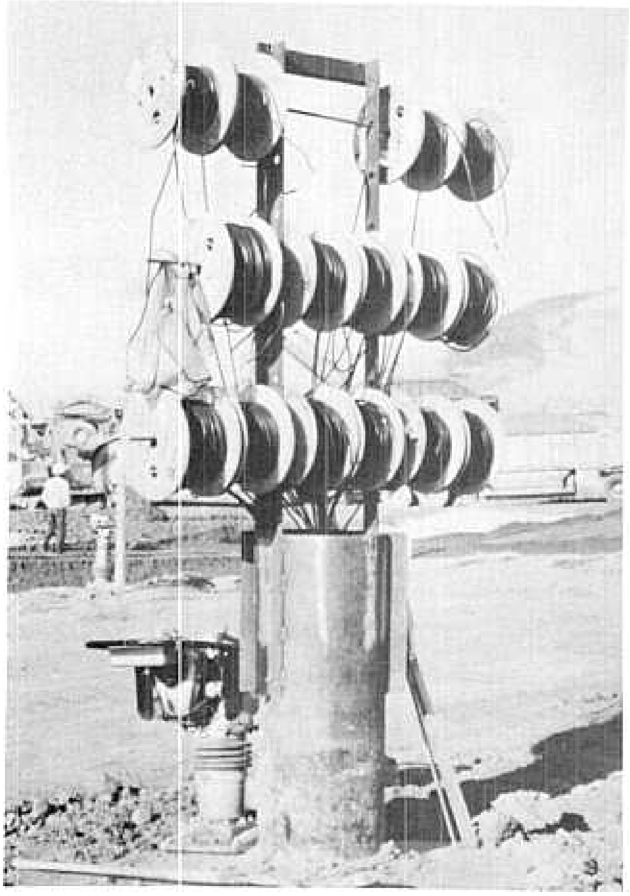


Figure 2-23.—Riser pipe used for installation of vertical piezometer tubing in an embankment. P801-D-81009.

resonant frequency of the wire, and a coil/magnet, which causes the wire to vibrate. Figure 2-26 shows details of this device, which is available in pressure ranges from 25 to 1,000 lb/in^2. The 250-lb/in^2 lower range unit is normally used for USBR dams. Specification EDI–12 (app. A) describes this equipment.

(2) *Electrical Cable.*—Each vibrating-wire piezometer is furnished with enough electrical cable for the required length in the trenches, the length to the terminal location, 10 percent for slack, and 10 feet for each piezometer. Four conductor cables shielded with a neoprene jacket are used. Each cable should be permanently marked by the manufacturer every 25 feet with its associated piezometer number.

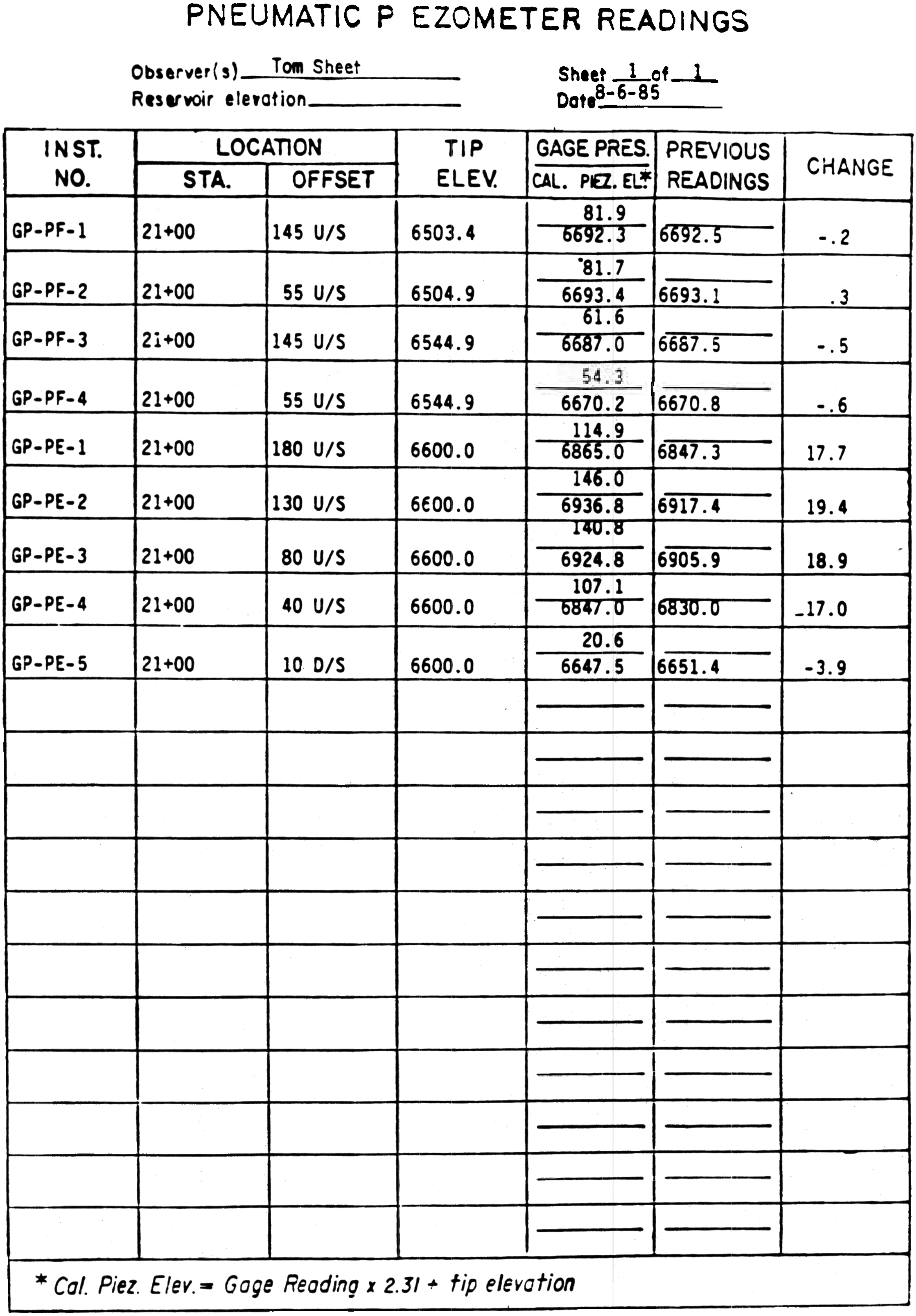
(3) *Readout Unit.*—Readout units must be able to accept an electrical signal from a vibrating-wire piezometer and display the frequency reading on a digital display. A battery charger and a supply of short electrical leads to connect the electrical cables to the readout unit are also required. See Specification EDI–13 (app. A) for details.

(4) *Backfill Material.*—Typical VWP installation backfill material consists of graded sand, bentonite pellets, and a bentonite-sand mixture. See section 31-d for details on backfilling procedures.

d. ***Installation.***—(1) *Installation in Drill Holes.*—Hole drilling and cleanout should be performed. The following tasks should also be completed:

(a) The sintered stainless steel filter on the end of each piezometer must be purged of air before installation (see fig. 2-27). This is done by removing the filter from the piezometer and submersing it in a bath of boiling water. (The O-ring must first be removed from the filter housing.) The zero reading should be taken at this time.

(b) Reassemble the piezometer under cool water, as shown on figure 2-28. The best way to do this is to place the filter, with the relatively small amount of hot water in which it was boiled, into a large bucket of cool water. The bucket should be large enough to allow the piezometer to be reassembled and bagged (as described below), while it is kept submersed at all times.



PNEUMATIC PIEZOMETER READINGS

Observer(s) Tom Sheet Sheet 1 of 1

Reservoir elevation________ Date 8-6-85

INST. NO.	LOCATION		TIP ELEV.	GAGE PRES.	PREVIOUS READINGS	CHANGE
	STA.	OFFSET		CAL. PIEZ. EL.*		
GP-PF-1	21+00	145 U/S	6503.4	81.9 6692.3	6692.5	-.2
GP-PF-2	21+00	55 U/S	6504.9	81.7 6693.4	6693.1	.3
GP-PF-3	21+00	145 U/S	6544.9	61.6 6687.0	6687.5	-.5
GP-PF-4	21+00	55 U/S	6544.9	54.3 6670.2	6670.8	-.6
GP-PE-1	21+00	180 U/S	6600.0	114.9 6865.0	6847.3	17.7
GP-PE-2	21+00	130 U/S	6600.0	146.0 6936.8	6917.4	19.4
GP-PE-3	21+00	80 U/S	6600.0	140.8 6924.8	6905.9	18.9
GP-PE-4	21+00	40 U/S	6600.0	107.1 6847.0	6830.0	-17.0
GP-PE-5	21+00	10 D/S	6600.0	20.6 6647.5	6651.4	-3.9

* *Cal. Piez. Elev. = Gage Reading x 2.31 + tip elevation*

Figure 2-24.—Example data sheet for pneumatic piezometer readings.

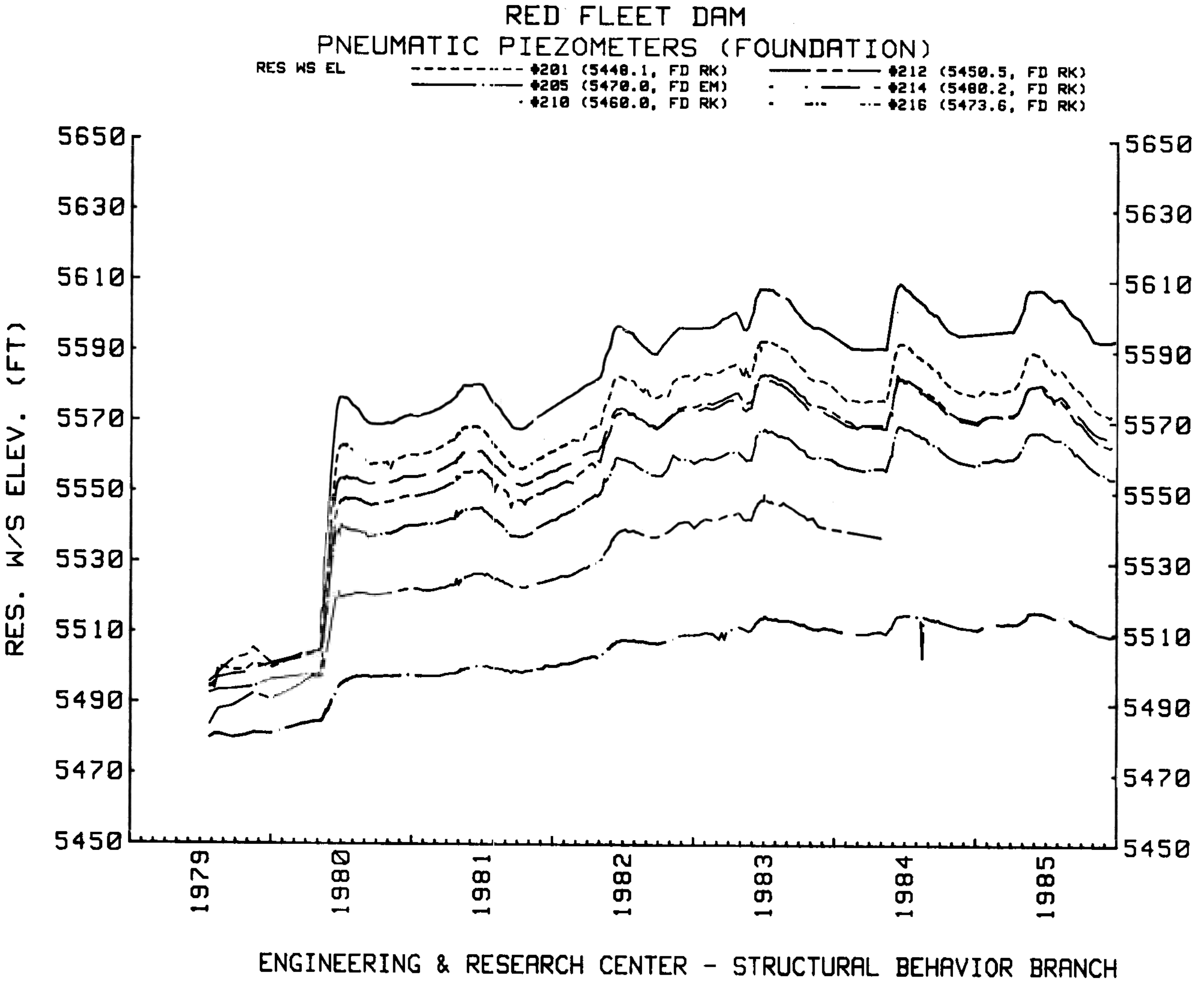


Figure 2-25.—Example plot of pneumatic piezometer data.

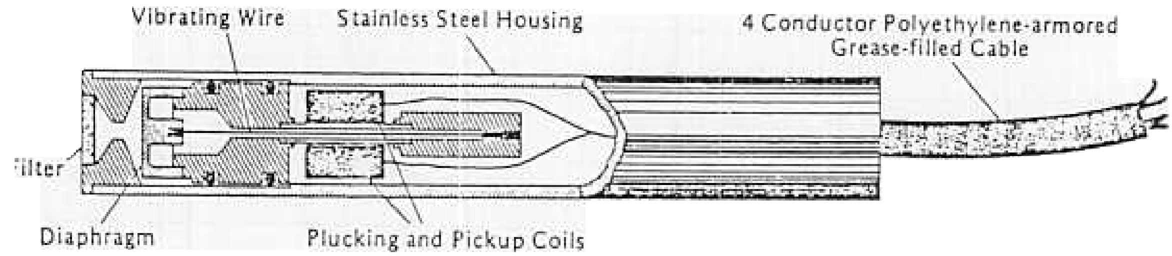


Figure 2-26.—Vibrating-wire piezometer tip assembly.

(c) Place a cloth bag in the bucket of cool water, then place some backfill sand in the bag. Place the piezometer in the bag and continue packing sand in the bag. Tie the top of the bag shut and wrap the bag with the wire-mesh screen. This entire unit should be kept submersed until the hole is ready for installation.

(d) Because all piezometers have different calibrations, noting the position of each piezometer installed is very important. Thus, the transducer numbers must be recorded.

When the hole is drilled to a depth of 1 foot below the desired piezometer elevation (for hole diameter see EDI-14), a temporary or steel casing pipe should be installed. This temporary casing is usually removed

Figure 2-27.—Vibrating-wire piezometer equipment. P801-D-81010.

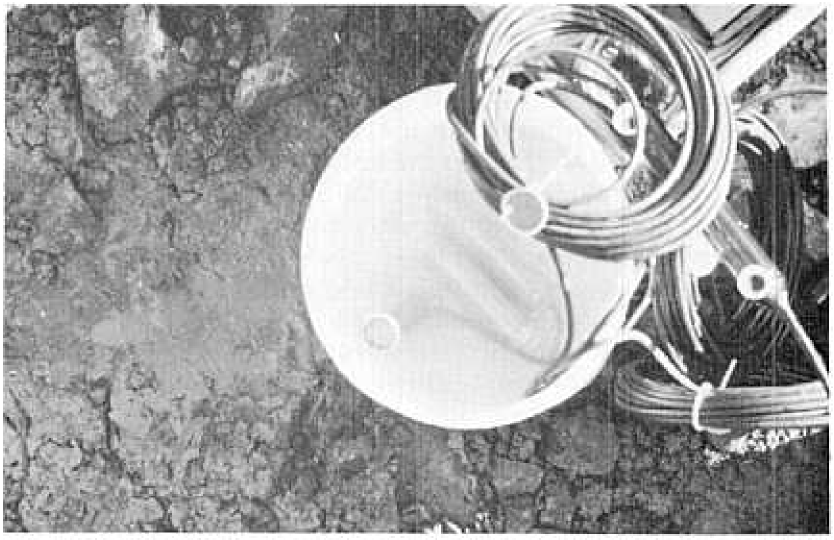


Figure 2-28.—Reassembling vibrating-wire piezometer under cool water. P801-D-81011.

in 1-foot increments just before backfilling. Then 1 foot of saturated, graded sand is placed at the bottom of the hole and compacted with a tamping rod (i.e., remove 1 foot, backfill 1 foot). The tamping rod can be one of many different items: blast loading rods, PVC pipe, or a tamping hammer.

During installation of the piezometer, the most important considerations are to set the piezometer at the proper elevation (so that the correct material will be monitored and the correct piezometric elevation will be indicated) and to avoid bridging the hole with the backfill material. To check both of these considerations during installation, a depth probe (usually a steel survey chain with a weight attached) should be used. Periodic depth measurements should be made, such as at the bottom of the hole, after 1 foot of sand has been compacted, at completion of the influence-zone backfill, at completion of the bentonite seal installation, and before the next piezometer tip elevation (if any) is reached in the hole.

A piezometer is then lowered into the hole to the desired elevation and tested. If it is operating properly, installation continues and the remainder of the influence zone is backfilled with specially graded, compacted sand to a point 2 feet above the top of the piezometer.

Above this level, a bentonite pellet seal is then backfilled and compacted. Between different piezometer levels in the drill hole, a backfill consisting of concrete sand, pea gravel, or cement grout should be placed. Cement grout should be used only when backfilling through a zone 1 material and should be placed only through a tremie pipe. The higher-level piezometer installation should begin with the installation of a 5-foot bentonite seal to separate the lower portion of the drill hole from the higher piezometer. The entire process should then be repeated for any higher-level piezometers to be installed in that drill hole. After the upper bentonite pellet seal is compacted, all slack in the wire leads should be removed, and the hole backfilled with a 3:1 mixture of sand and cement. After backfilling is complete, the casing is then pulled.

(2) *Installation in Offset Trenches.*—Piezometers installed in an embankment differ from those installed in drill holes because they are not installed in sand-filled bags and they may use a ceramic filter. Piezometers are often installed in offset trenches leading from main trenches excavated into the embankment. The piezometer tips are placed on a 3-inch compacted layer of material from the zone through which the trench is excavated. This 3-inch layer is compacted to the same density as the surrounding embankment. Embankment fill material should not be compacted until a 9-inch thickness is placed over the piezometer tip. The compaction effort must be carefully conducted to avoid damage to the piezometer tip. Fill or backfill may not be placed over the piezometer tip or the electrical cable until the piezometer has been tested successfully. Instrumented offset trenches and main trenches with electrical cables are backfilled as indicated on figure 2-20. The trench backfill material should be 3:1 sand-bentonite mixture around the cables, and the material from the zone through which the trench is passing for the remainder of the trench. Cutoffs are required and should be constructed as discussed in section 31-d.

e. ***Monitoring Procedures.***—Vibrating-wire piezometers are supplied with a reference reading that corresponds to the period (inverse frequency) of the initial wire tension set at the factory. The barometric pressure is also provided. Upon arrival, the initial gauge readings should be checked. Orange and blue lead wires are for the pressure transducer and, when included, white wires connect to a thermistor. For example, to check the initial reference reading on IRAD-type gauges, set the gauge select or switch to GAUGE TYPE 3, set the mode switch (where present) to NORMAL, connect the leads to the piezometer (it is not important which wire is connected to which color), and note the reading. This reading (new zero reading) should lie within 20 units of the reading supplied with the gauge. The exact difference will depend on the temperature and barometric pressure at the test site and the scale range of the device.

The piezometer tips are sealed during manufacture, and corrections for barometric pressure differences are sometimes required. These corrections can be made by adding the difference between the site barometric pressure and the barometric pressure noted at the time of factory calibration to the calculated pressure.

All vibrating-wire piezometers are individually calibrated before shipping, and a calibration graph, gauge factor, and initial reading are supplied with each unit.

The basic relationship between the deflection of the piezometer diaphragm and the vibration frequency or period of vibration of a vibrating wire attached to it is:

$$\text{Deflection} = \text{constant} \times (\text{frequency})^2 = \text{constant} \div (\text{period})^2 \qquad (1)$$

where the constant takes into consideration the diameter and length of the wire. Because pressure is proportional to the diaphragm deflection, the relationship between the applied pressure, P, and that of the readout unit can be expressed by an equation similar to the following:

$$P = G\,(L_o - L_l) \qquad (2)$$

where:

P = pressure, in pounds per square inch,
G = gauge constant (gauge factor) supplied with piezometer, in pounds per square inch per linear unit,
L_o = initial zero reading under zero pressure at site during installation, and
L_l = reading under actual pressure at site.

The initial zero reading has been recorded at the time of piezometer installation, and only a new L_l reading is required to use the formula. Alternatively, for approximate pressure values, a calibration graph similar to figure 2-29 can be used directly. The pressure is simply scaled off the graph. Similarly, temperature corrections can be made using a temperature constant supplied with the unit as follows:

$$PT_l = G(L_o - L_l) - K(T_o - T_l) \tag{3}$$

where:

K = temperature constant supplied,
T_o = initial temperature (°F) at calibration (supplied by manufacturer), and
T_l = current temperature (°F) of piezometer at site.

Specific instructions for reading an IRAD gauge (Model MB-6-LU) readout box are:

(1) Plug the jumper leads into the top panel of the MB-6-LU.

(2) Attach the clips on the jumper leads to the blue and orange leads of the piezometer cable (sequence is not important). (The white leads are the thermistor leads.)

(3) Set the gauge type switch on TYPE 3.

(4) Set the AUTO/MANUAL switch on AUTO.

(5) Set the NORMAL/LINEAR switch on LINEAR.

(6) Turn the power ON.

(7) The reading will be displayed as a four-digit number. Record this number (without decimals); this is the L_l reading.

(8) If a colon appears in the display, the unit needs charging. Charging should not be continued for more than 16 hours.

(9) The unit will shut off in approximately 4 minutes if unattended.

f. ***Data Processing.***—The pressure readings obtained from the formula $P = G(L_o - L_l)$ are in pounds per square inch. These readings should be converted to the actual piezometric elevation by multiplying them by a factor of 2.31 to obtain pressure in feet of water, then algebraically adding this value to the tip elevation. Figure 2-30 shows a sample data sheet.

The data are transmitted to the Structural Behavior Branch for analysis. Upon arrival, the data are processed, reviewed, and reported as discussed in section 25. An example plot of vibrating-wire piezometer water pressures is shown on figure 2-31.

33. Resistance Strain Gauge Piezometers.—a. ***Usage.***—Resistance strain gauge piezometers, which measure pore-pressures, have been installed at only one USBR embankment dam (Ririe Dam[15]), and there are no current plans for future installations. At Ririe Dam, 21 cells were installed in 1976, and as of 1986, 16 are still functioning with 6 of these piezometers indicating questionable data.

b. ***Advantages and Limitations.***—The advantages of this type of pore-pressure measuring device are the same as those of most types of closed system electrical piezometers: Readout location is independent of cell location, no freezing problems occur, etc. (see table 1-1). The limitations are mostly related to the problem of measuring minute resistance changes. Some influencing factors include cable lengths, splices, isolation from ground, contact resistance, etc. Extra precautions and proper techniques are required during installation and readout.

c. ***Description of Equipment.***—In a resistance strain gauge piezometer, water pressure is admitted to an internal diaphragm through a porous disk that prevents soil particles from entering. The deflection of the internal diaphragm is measured using an elastic-wire electrical resistance device as the sensing element. This device is a strain meter that consists of two coils of fine-steel wire wound on ceramic spools. One of the coils increases in length and resistance with strain, while the other decreases.

The change in resistance is caused mainly by stress and not by the change in the dimensions. The ratio of electrical resistance of the two coils is directly proportional to the change in gauge length; whereas, the total resistance of the two coils is directly related to temperature. The temperature must be determined to compute the proper resistance ratio within the calibration range of the device. Both the ratio and the total resistance may be accurately measured using a Wheatstone bridge readout unit to 0.01 percent and 0.01 ohm, respectively.

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[15] Ririe Dam is an earth and rockfill dam, 253 feet high and 1,070 feet long. It was designed and constructed by the U.S. Army Corps of Engineers on Willow Creek in Bonneville County, Idaho.

PIEZOMETER CALIBRATION

Date 10 March 83

Model No. 4500S

Temp. 64.4

Serial No. 255T-100

Barometer 29.86

Gauge Factor, G .0499

Zero Rdg., L_0 3273

Temp. Coeff., C .0025 PSI/°F

Period, T_0 5527

Pressure + (L_0 - L_1 G

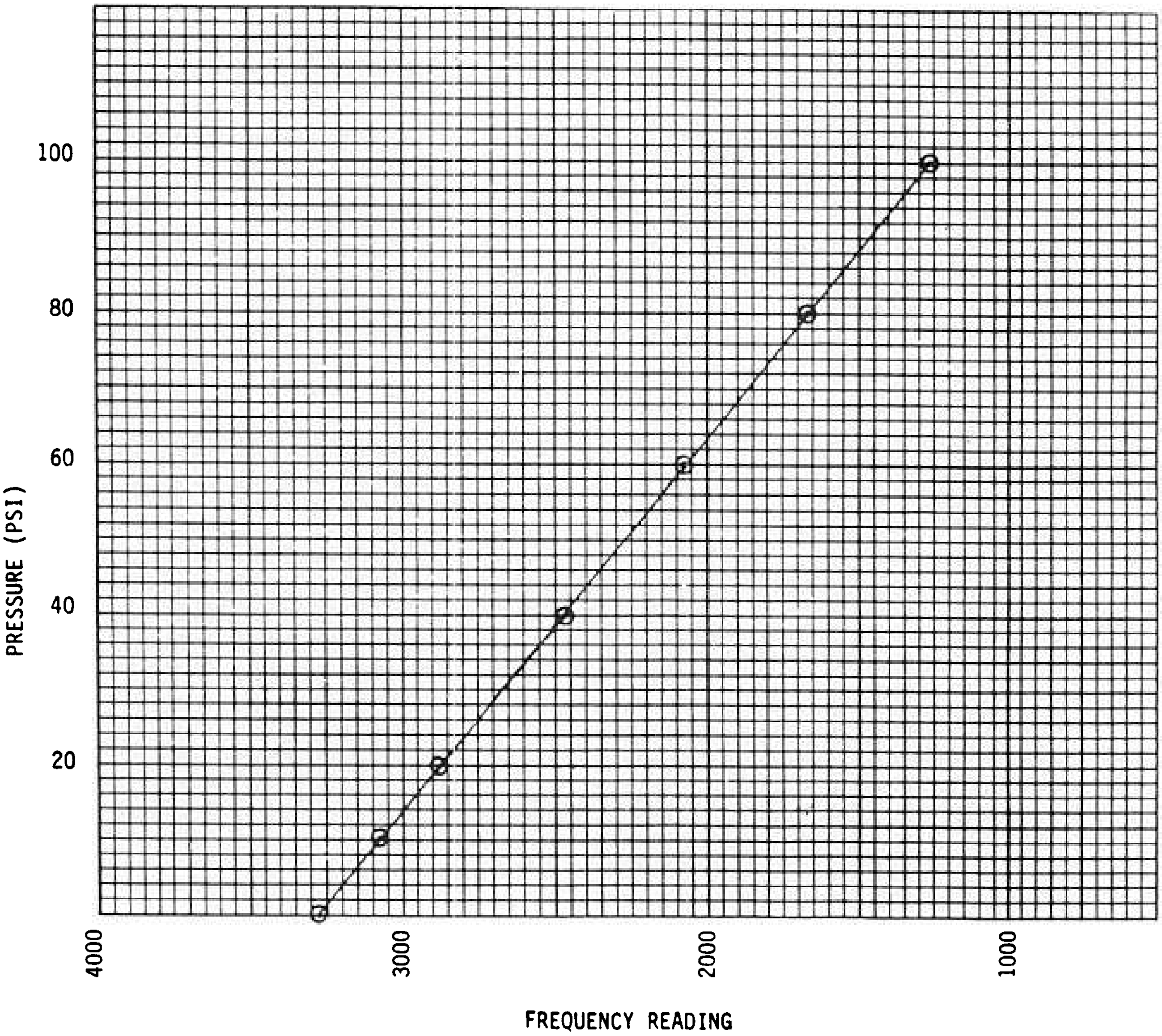


Figure 2-29.—Typical calibration graph for vibrating-wire piezometer.

Vibrating-Wire Piezometers

OBSERVER(S) Dave Sheet
RES. ELEV. 435.68
TAIL WATER ELEV.

SHEET 1 OF 1
DATE 7-23-85

PIEZO. NUMBER	DEPTH	GAGE FACTOR	L_0	$\frac{T_1}{L_1}$	(L_0-L_1)	PRESSURE $[G(L_0-L_1)]$	HEAD x 2.31	PRESSURE CHANGE	TIP ELEV.	PIEZOMETRIC ELEVATION	TOP OF GROUND ELEV.	
VW-40-2A	69.0	.2200	2862	6045 2779	83	18.2	42.18	.05	436.1	478.3	505.1	
VW-40-2B	77.0	.1900	2840	6095 2734	106	20.1	46.5	1.0	428.1	474.6	505.1	
VW-58-3A	46.30	.2860	2817	6092 2737	80	22.88	52.85	1.1	380.8	433.75	427.1	
VW-58-3B	54.0	.1800	2865	6017 2806	59	10.62	24.53	2.0	373.1	397.6	427.1	
VW-60-1A	18.80	.2800	2698	6267 2586	112	31.36	72.44	5.1	364.7	437.1	383.5	
VW-60-1B	31.80	.2700	2667	6306 2554	113	30.51	70.48	4.3	351.7	422.18	383.5	

T_1 is present instrument reading
L_0 and L_1 are from tables
REMARKS:

Figure 2-30.—Example data sheet for vibrating-wire piezometer readings.

The sensing elements are immersed in corrosion-resistant oil, with a small amount of air to allow for expansion. In addition to protecting the wire coils, the oil acts as a heat sink reducing the effect of heating when readings are taken. Specification EDI-14 (app. A) covers this device.

d. ***Installation.***—The resistance strain gauge piezometer may be installed in a drill hole or in an embankment as construction progresses. Installation procedures are identical to those described in section 32–e.

e. ***Monitoring Procedure.***—The monitoring procedure for one type of resistance strain gauge piezometer, the Carlson pore-pressure cell, is described below.

(1) Connect the wire leads from the cell to the readout instrument. Each of the three wire leads should be connected to the terminal of the same color. (Some devices use a four-wire system for ease of temperature reading.) Each plug is grooved and can only be inserted one way.

(2) Turn the instrument on and adjust the indicator needle to zero.

(3) To read the resistance, set the selector switches to RESISTANCE and 2L. Depress the test button for an instant. (Do not hold it down, or current flow will generate heat and change the resistance value.) Note the direction of needle deflection. Adjust the rheostat setting until the indicator needle does not deflect when the test button is depressed momentarily. Read and record the rheostat dials.

(4) Switch one selector switch to the RATIO position and follow the procedure in (3) above to obtain the resistance ratio.

(5) To reduce the reading time and wear on the instrument, use the reading obtained the last time the instrument was read as a starting point for setting the dials.

(6) Record all the data on the field data form, as shown on figure 2-32.

f. ***Data Processing.***—The data forms should be forwarded to the Structural Behavior Branch for processing and review as described in section 25. The data are processed on the computer using formulas containing several constants, including tip elevation, temperature constant, resistance constant, ratio constant, and other parameters determined at the factory during calibration. Data plots are then prepared.

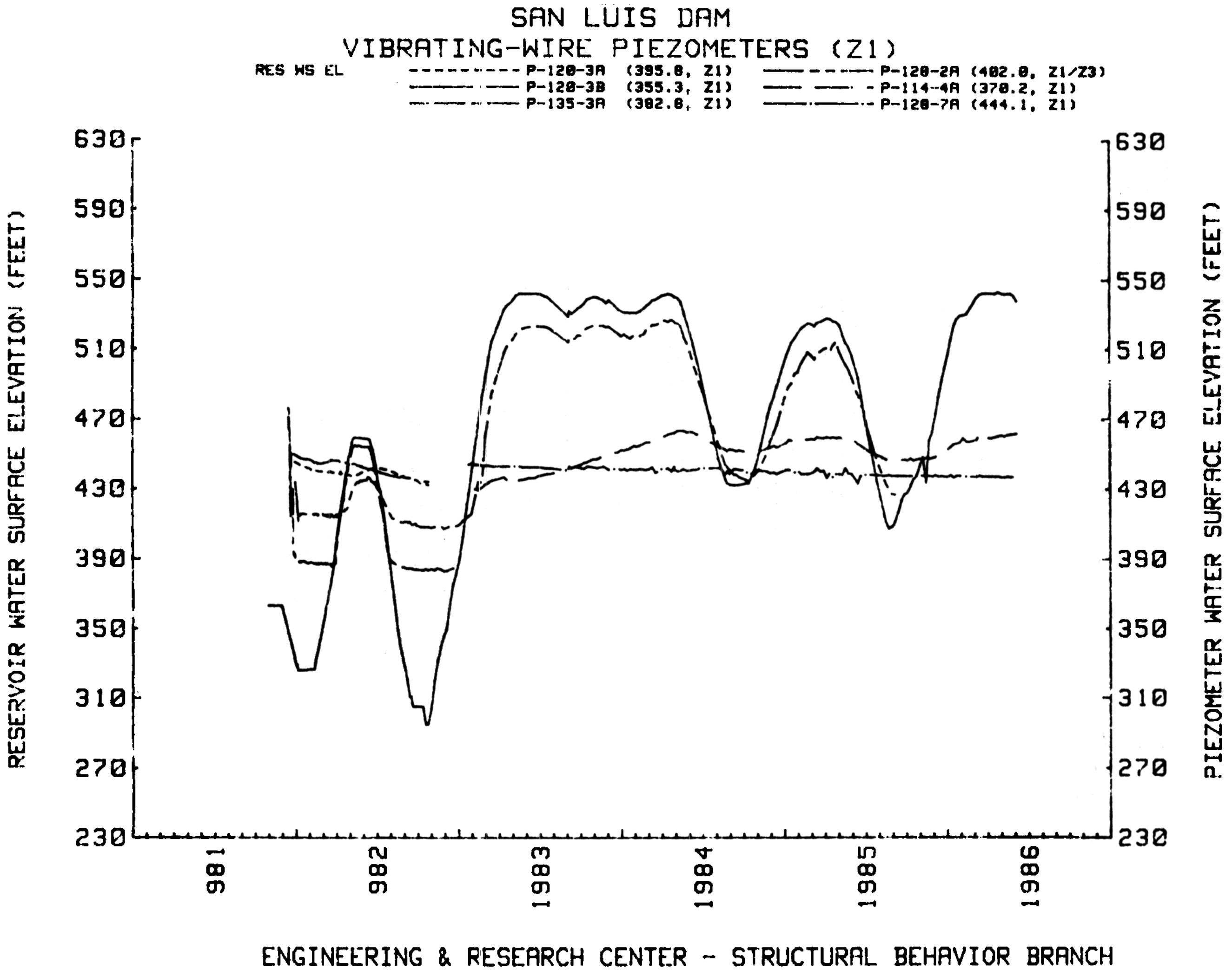


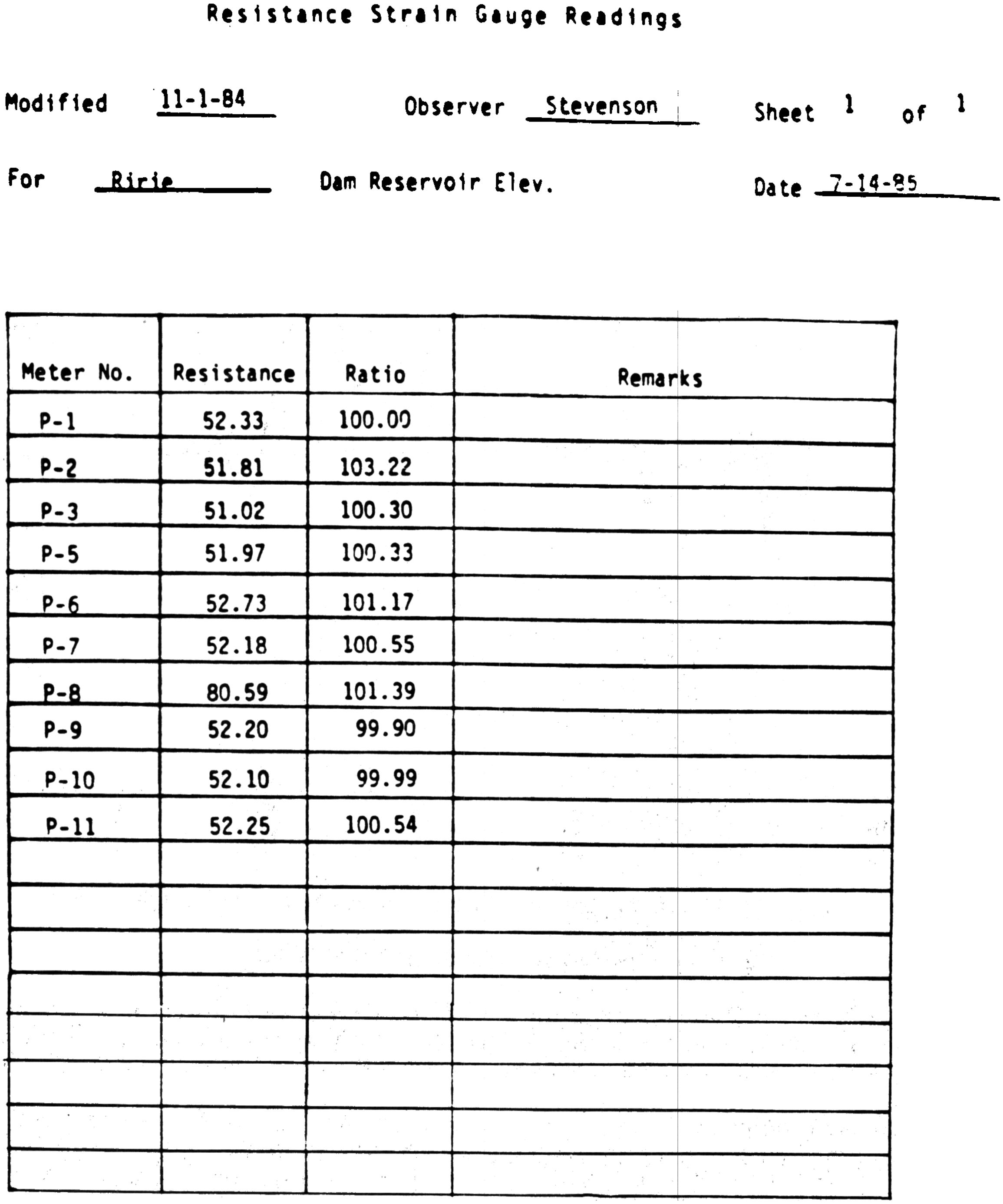
Figure 2-31.—Example plot of vibrating-wire piezometer data.

34. Total Pressure Cells.—a. ***Usage***—Pneumatic and vibrating-wire total pressure cells are used to monitor the static total (soil and water) pressure in an embankment dam. Total pressure cells measure the stresses in the embankment or the foundation and the stresses against the surfaces of concrete conduit or other appurtenant structures.

b. ***Advantages and Limitations.***—Both pneumatic or vibrating-wire total pressure cells have several advantages including easy readout, a relatively short response time in reading, and no freezing problems. In addition, the level of the tubes and readout terminal are independent of the level of the pressure cell and they allow the use of the central observation system.

Significant limitations to the use of pneumatic or vibrating-wire total pressure cells include the fact that they have been used only a short time, and their long-term durability has not been proven. In addition, a piezometer must be located near the pressure cell so that the water pressure portion may be subtracted from the total pressure to determine the static earth pressure.

The principal difficulty with either type of total pressure cell is that it is essentially impossible to measure representative earth pressure in an embankment because the installation procedure involves cutting a trench and backfilling above and around the device. Even after careful installation and compaction, the soil around the device is in a different condition than the remainder of the embankment. Therefore, the pressures measured may or may not be representative of pressures in the adjacent embankment. The USBR's attempts to develop a method of checking the finite element design stresses in an embankment using total pressure cells have not been successful. However, because pipes, concrete structures, or vertical faces of abutments already represent



Resistance Strain Gauge Readings

Modified 11-1-84 Observer Stevenson Sheet 1 of 1

For Ririe Dam Reservoir Elev. Date 7-14-85

Meter No.	Resistance	Ratio	Remarks
P-1	52.33	100.00	
P-2	51.81	103.22	
P-3	51.02	100.30	
P-5	51.97	100.33	
P-6	52.73	101.17	
P-7	52.18	100.55	
P-8	80.59	101.39	
P-9	52.20	99.90	
P-10	52.10	99.99	
P-11	52.25	100.54	

Figure 2-32.—Example data sheet for resistance strain gauge piezometer readings.

a structural discontinuity containing at least two different materials, pressure cells attached to the faces of such structures can effectively measure embankment pressures acting on them.

The vibrating-wire total pressure cell operates in the same manner as the vibrating-wire piezometer, which is described in section 32. Therefore, the remainder of this section is devoted to the pneumatic total pressure cell.

c. ***Description of Equipment.***—A pneumatic total pressure cell device consists of a pressure cell, pneumatic pressure transducer, tubing bundles, tube bundle terminal assembly, portable pneumatic pressure indicator, terminal panel, riser pipes, and backfill material. All but the pressure cell and transducer have been described in section 31–c.

(1) *Pressure Cell.*—The pneumatic total pressure cell (fig. 2-33) consists of two 9-inch-diameter stainless steel plates welded together at the outer edge. The space between the plates is filled with de-aired lightweight oil. The liquid center reacts to external pressure on the plates by pushing against a rubber diaphragm in an attached pressure transducer. The diaphragm is then warped, closing a vent tube. Pneumatic pressure is then applied from a readout unit air tube, returning the diaphragm to its original shape. The amount of pressure required to accomplish this is the static total pressure on the cell. Excess air pressure is vented to the atmosphere.

(2) *Pneumatic Pressure Transducer.*—The transducer contains a rubber diaphragm that has negligible spring force. It requires a constant flow of air to be maintained while readings are taken. This style transducer is referred to as a null-balance design. Specifications for acceptable pressure cells and transducer assemblies are in Specification EDI–15 (app. A).

d. ***Installation.***—(1) *Installation of Pneumatic Total Pressure Cells in Embankments.*—A typical pneumatic total pressure cell installation is shown on figure 2-34.

During construction, the embankment is carried above the proposed pressure cell locations. Trenches should then be excavated in the embankment as described in section 31–d.

Pressure cells installed in offset trenches must be placed on at least 3 inches of the zone material through which the trench is passing. This 3-inch layer should be compacted carefully to the density of the surrounding material. Material placed over the pressure cell must not be mechanically compacted until at least a 9-inch layer of the same zone material has been placed over the cell. Offset trenches are backfilled as indicated on figure 2-20.

(2) *Installation of Tubing or Cables.*—The tube bundles or cables should be placed in layers in both offset and main trenches. All testing of the units must be completed before any layer of tube bundles is covered.

Backfill material consisting of bentonite and concrete-sand material should be placed and compacted on the bottom of the trenches, as described in section 31-d.

(3) *Installation of Cells on Structures.*—Total pressure cells placed against a structure are installed in recesses formed into the structure during construction. These recesses must be large enough to hold the entire total pressure cell (transducer and plates). Each recess is sandblasted, then epoxy-coated. A pad of cement mortar, two parts sand to one part cement (quicksetting, nonshrinking), is troweled onto the concrete surface of the recess to make a flat surface. The nonreactive surface of the total pressure cell is pushed into this pad, squeezing out mortar until a layer ¼-to ½-thick remains beneath the cell. A typical pressure cell installed against a structure is shown on figure 2-35. The installation is then examined for entrapped air bubbles. The tubes or cables are secured to the concrete so that the cell will remain in a fixed position. Extra tubing or slack in the cables is provided to allow for embankment compaction and to minimize tension on the leads. The fill is compacted over the total pressure cell to the same density as the surrounding material. During this installation, the reactive surface of the cell is oriented toward the embankment materials.

e. ***Monitoring Procedure.***—One type of pneumatic total pressure cell used, that of the Slope Indicator Co., normally uses a two-tube configuration. This configuration consists of one black tube and one clear tube. The black tube is the input tube, which is connected to the input coupler on the indicator panel, and the clear tube is the output tube, which is left uncapped and vented to the atmosphere. The monitoring procedures are the same as those previously discussed in section 31–e.

f. ***Data Processing.***—The pressure readings obtained are in pounds per square inch. A sample data sheet is shown on figure 2-36. The data are transmitted to the Structural Behavior Branch for processing and review as outlined in sections 25–c and 25–d.

The plots prepared consist of a record of pressures acting on each cell over a period of time (see fig. 2-37).

C. Open System Instrumentation

35. Porous-Tube Piezometers.—a. ***Usage***—PTP's (porous-tube piezometers) are used to measure water pressures in embankments, foundations, or abutments in selected zones of materials. The PTP's may be installed in drill holes or installed in an embankment during construction.

The selection of a porous-tube piezometer over a slotted-pipe piezometer is usually based on the grain size of the materials at the measuring elevation (influence zone); fine-grain materials could plug a slotted pipe. Porous-tube piezometers are also used where measuring the water pressure in a relatively small zone of materials or checking measurements for closed system piezometers is desired.

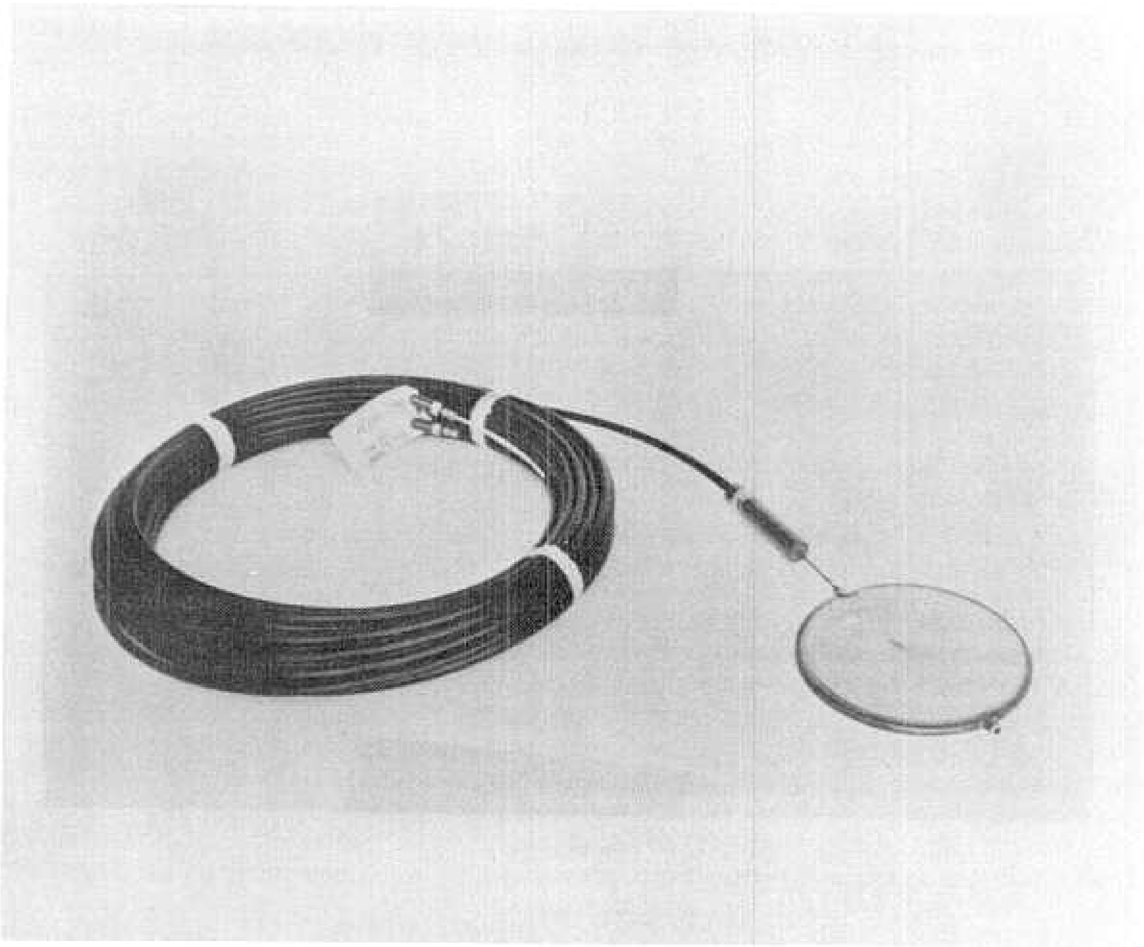


Figure 2-33.—Pneumatic total pressure cell. P801-D-81012.

b. ***Advantages and Limitations.***—The advantages of porous-tube piezometers include simple operation, relatively inexpensive installation (although drilling can be costly), reliability, no metallic or mechanical parts to corrode, a long and successful performance record, and essentially no maintenance requirements. In addition, the data taken from the piezometer can be used directly by the reader with few or no mathematical calculations required.

A very important advantage of a standpipe-type piezometer is that if excess water pressures have been introduced during drilling and installation operations they can be removed. With a pneumatic or vibrating-wire piezometer this can not be accomplished and the data is erroneous until this excess water pressure has dissipated.

Porous-tube piezometers have the following advantages:

- The permeable intake space can be positioned to isolate water pressures occuring in a stratum of limited thickness, even though such pressures may exceed the hydrostatic pressure. If excess hydrostatic pressure raises the water level above the top of the plastic standpipe, additional riser sections or a hydrostatic Bourdon gauge can be installed.
- The PTP installation is fabricated from durable, inert materials that are unaffected by deterioration or corrosion.
- Simple tests can be performed on the PTP after installation to appraise its sensitivity and approximate the average permeability of the soil surrounding the tip. A standard test should be performed once a porous-tube piezometer has been installed. In soils with low permeabilities, a small amount of water should be removed from the piezometer and the rate at which the water returns should be measured. In soils with high permeabilities, a small amount of water may be added and the time required for water to leave the piezometer should be measured. These tests will serve as a final acceptance test of the

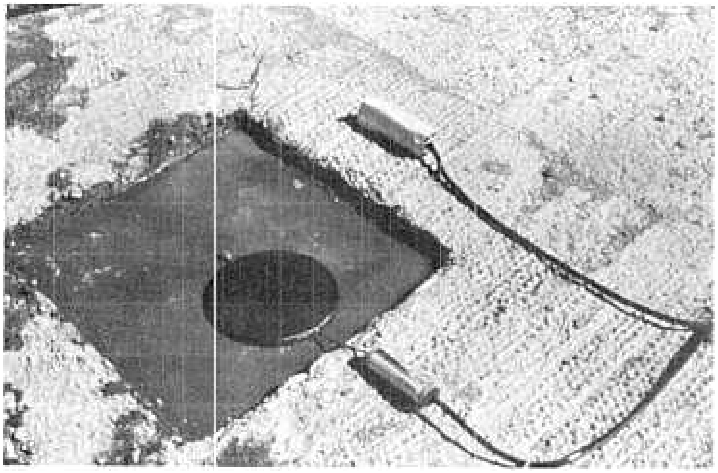


Figure 2-34.—Pneumatic total pressure cell installation. P801-D-81013.

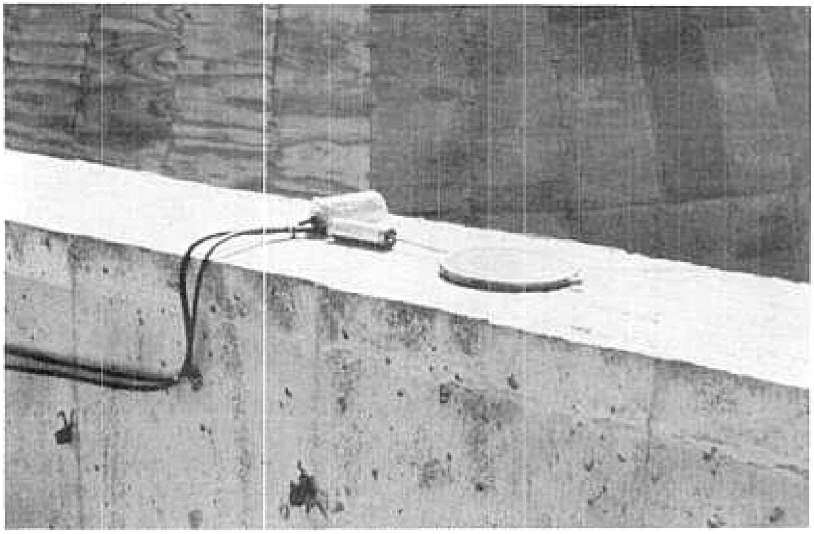


Figure 2-35.—Pneumatic total pressure cell installed against a structure. P801-D-81014

instrument and ensure that the instrument is functioning properly. Drill crews should be in the habit of performing these tests so when later anomalies in the data occur, precious time is not wasted determining whether the instrument was installed or ever functioned properly.

The limitations on the use of porous-tube piezometers include the fact that the porous filter can become plugged from repeated water inflow and outflow, the response time in reading is relatively long, and shallow systems may freeze. In addition, the standpipe may be damaged during construction or may interfere with construction equipment. The standpipe must extend nearly vertically (precluding use in monitoring areas beneath the reservoir), and alterations must be made if the piezometric level is above the top of the standpipe. Installations in silt are subject to problems resulting from the tendency of fine particles to penetrate into the sand backfill, reducing the sensitivity of the piezometer.

The sand backfill surrounding the porous tube should meet standard filter requirements as closely as possible without including any silt-size particles. The porosity of the porous tube can be selected from coarse, medium, or fine grades to inhibit the movement of particles from the surrounding soil through the tube.

Experience indicates that the performance of the porous tube is not entirely satisfactory in soils containing an appreciable air content. The presence of air in the soil voids decreases the average soil permeability from

Total Pressure Cell Readings

OBSERVER (S) Harkins
RES. ELEV.

SHEET 1 OF 1
DATE 7-23-85

Terminal well at station		
Press. cell No.	Gage reading	
	Flowmeter	Output press.
TPC-2A	.1	4.8
TPC-2B	.1	8.5
TPC-2C	.1	21.4
TPC-3A	.1	21.0
TPC-3B	.1	13.1
TPC-3C	.1	31.5

Terminal well at station		
Press. cell No.	Gage reading	
	Flowmeter	Output press.
TPC-4A	.1	5.6
TPC-4B	.1	10.7
TPC-5A	.1	20.5
TPC-5B	.1	40.3
TPC-6A	.1	10.7
TPC-6B	.1	9.9

Figure 2-36.—Example data sheet for pneumatic total pressure cell piezometer readings.

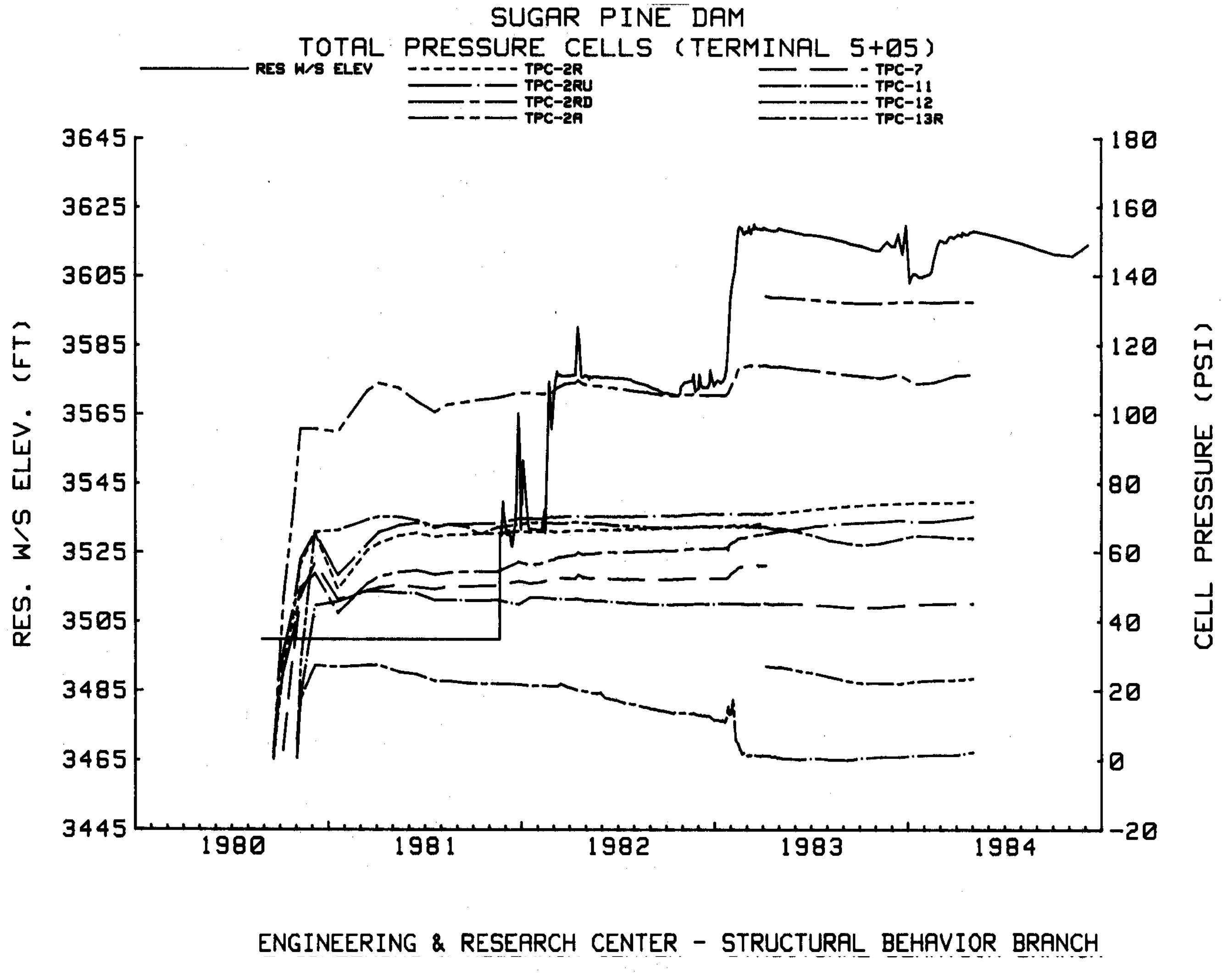


Figure 2-37.—Example plot of pneumatic total pressure cell piezometer data.

that of a completely saturated condition. The air also decreases the permeability of the porous tube. Thus, changes in the volume of air that accompany pore-pressure fluctuations tend to retard the flow of water into the standpipe and slow the piezometer's response. The porous tube and the sand backfill must be saturated during installation.

To isolate hydrostatic pressures in a relatively thin aquifer, it may be necessary to limit the length of the porous space. Although this sacrifices sensitivity, some of the effects can be offset by using a larger diameter hole or influence zone.

c. ***Description of Equipment.***—Porous-tube piezometers consist of a porous-tube assembly, protective casing, standpipe, backfill material, water level indicator, and a protective cover pipe. Figure 2-38 illustrates a typical installation. A conventional porous-tube installation contains a single standpipe, but a two-tube system has been developed that provides an additional access if one standpipe becomes plugged. Such systems are, of course, more expensive for initial installation. They have not yet been used by the USBR.

(1) *Porous-Tube Assembly.*—Porous-tube assemblies may consist of alundum, carborundum, or high-density polyethylene porous tubes, a reducer bushing, and a pipe plug. Figure 2-39 shows typical construction details, and Specification EDI–16 (app. A) covers the requirements. The porous tube is normally cemented to the standpipe with liquid-weld cement.

(2) *Protective Casing.*—All porous-tube piezometers installed during embankment construction and some drill hole installations require a protective casing around the piezometer tip and standpipe. This protective casing is normally PVC (polyvinyl chloride) pipe. The casing should be perforated in the influence

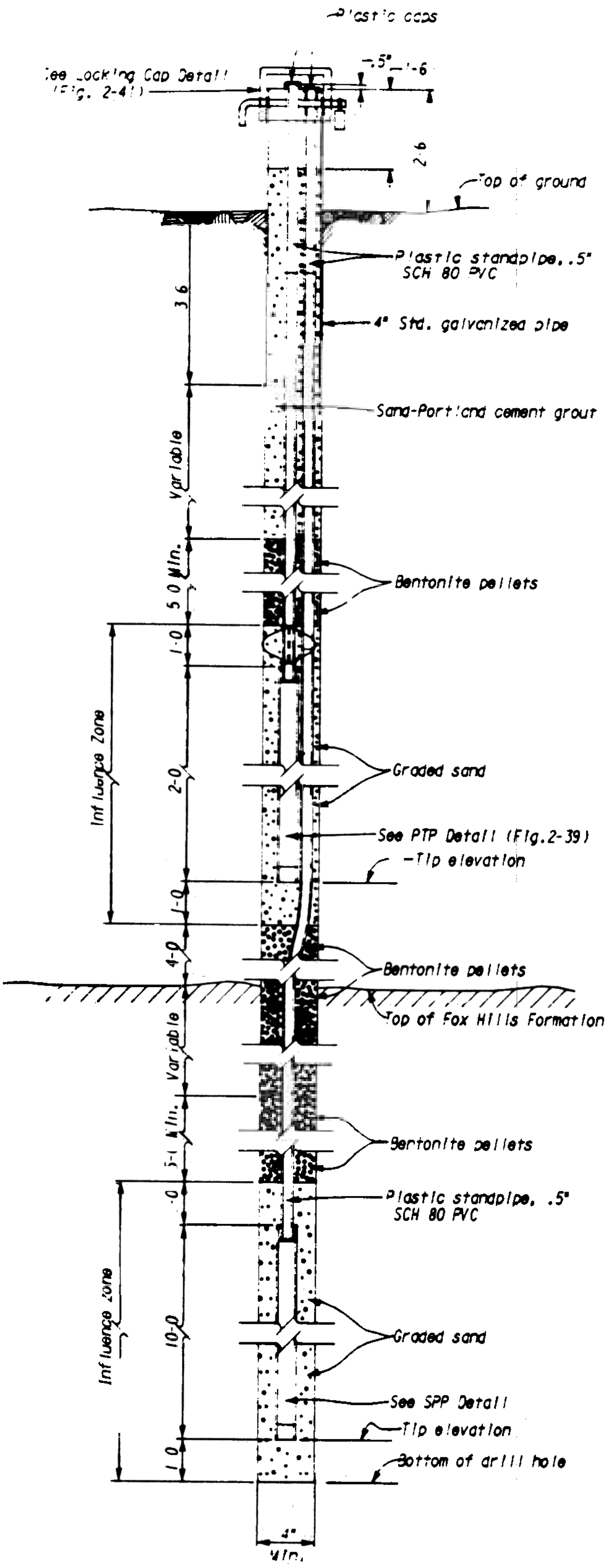


Figure 2-38.—Installation details for porous-tube or slotted-pipe piezometer and for observation well.

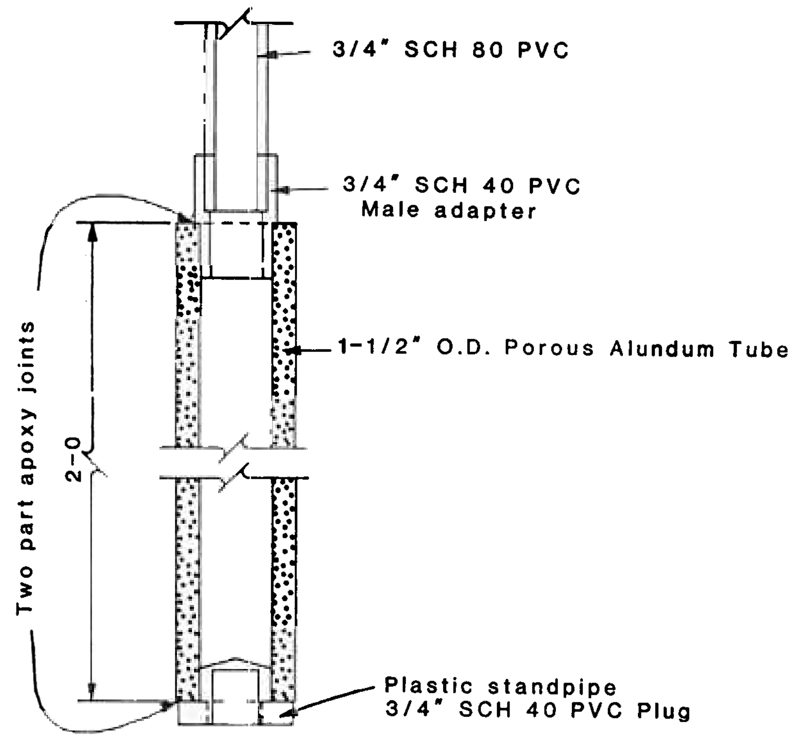


Figure 2-39.—Porous-tube piezometer assembly.

zone to be measured, and the perforations should be covered with metal screening and cloth or filter fabric to separate sand backfill from embankment materials. Figure 2-40 shows a typical installation during embankment construction, and Specification EDI–17 (app. A) describes the pipe materials.

(3) *Standpipe.*—The standpipe rising from the porous tube to the readout level should normally be constructed of ½- or ¾-inch-diameter PVC pipe furnished in straight sections. Using ⅜-inch-diameter pipe furnished on rolls has caused problems with unrolling in cool weather, and the tendency for this pipe to kink has caused the water level probe to stick. Although they are slightly more expensive, threaded internal couplings are recommended over slip couplings for several reasons: They are easier to install and do not present the problems encountered using liquid-weld cement on slip couplings in cold weather; and some slip couplings are poorly machined, allowing the cement to cause internal pipe obstructions. These and other disadvantages of slip couplings, including the time required to apply the cement and wait for the connection to bond, the potential hazard of standpipe separation, which could destroy an installation, and the unnecessary obstruction in the hole caused by external couplings make threaded couplings the obvious choice. Specifications for the standpipe are in Specification EDI–18 (app. A).

In some cases, observation wells and piezometers are installed in drill holes also used for exploration, sampling or other purposes. In these cases, it may be desirable to use 2-inch-diameter (or larger) slotted-pipe and standpipe to accommodate the probe on a portable electric logger. However, it should benoted that larger diameter standpipes will result in less sensitivity to ground-water changes, particularly in soils of lower permeability.

(4) *Protective Cover Pipe.*—A pipe of 4-inch minimum diameter and 6-foot length is recommended for use as a protective pipe at the surface readout level. This pipe should be schedule 40 galvanized steel with a 5-inch cap with a locking device. Non-threaded caps are available. If a threaded cap is used, the threads should be oiled frequently and the cap screwed on all the way and then backed off. Figure 2-41 shows this pipe cover.

(5) *Water Level Indicator.*—The water level in the standpipe is determined using a battery-powered water level indicator, which consists of a self-contained reading unit and a probe. When the probe encounters water, an electrical circuit is closed; this is indicated by a dial, light, or sound. The depth to the water should then be read from the marked wire leading to the probe. Specification EDI–19 (app. A) describes this unit.

(6) *Backfill Material.*—Graded sand, bentonite pellets, and concrete sand are normally required for use as backfill. See section 35-d(2) for details.

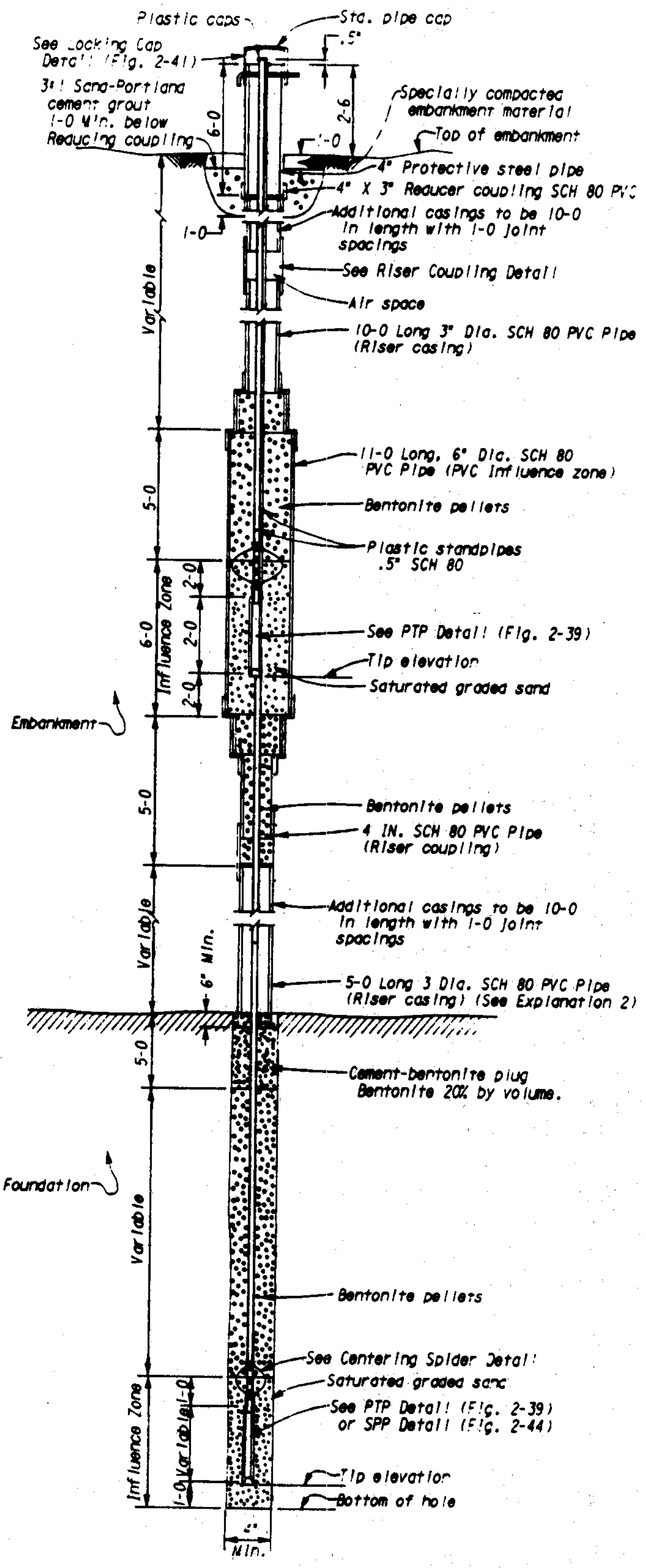


Figure 2-40.—Double piezometer installation details.

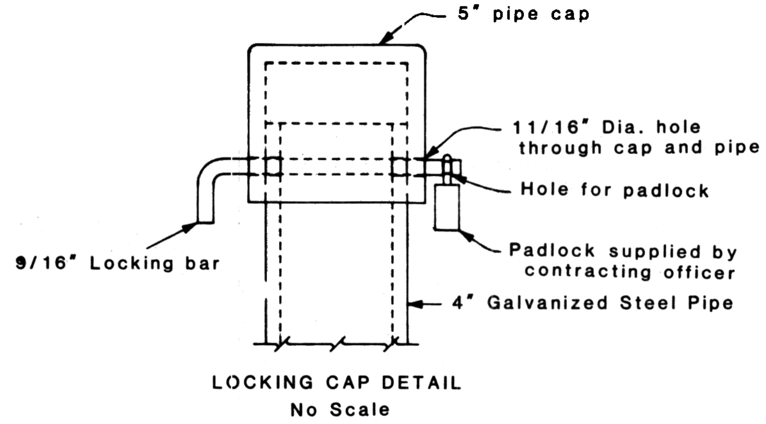


Figure 2-41.—Locking cap for porous-tube piezometer.

d. ***Installation.***—(1) *Installation in Drill Holes.*—The hole drilled for a relatively deep single porous-tube piezometer should be at least 4 inches in diameter to allow adequate room for sand backfill. A double piezometer system should preferably be installed in a 6-inch-minimum-diameter hole to allow adequate room to seal the upper piezometer influence zone because of the additional standpipe. Triple installations are not recommended because of the problems of sealing around three separate influence zones.

Minimum drill hole size requirements are as follows:

Total depth of drill hole	One piezometer to be installed in hole	Two piezometers to be installed in hole
0- 50 feet	3-inch-diameter	4-inch-diameter
50-150 feet	4-inch-diameter	4-inch-diameter
150-300 feet	4-inch-diameter	6-inch-diameter
over 300 feet	Determined on case-by-case basis by Structural Behavior Branch	

When porous-tube piezometers are installed in drill holes, the hole should be advanced to about 1 foot below the planned piezometer elevation. The hole is then prepared for installation by bailing as much water from the hole as possible. Bailing allows an easier and probably faster installation and prevents drill water from artificially inducing erroneous data following installation.

The hollow-stem auger or casing should usually be removed in 1-foot increments just before the hole is backfilled (i.e., remove 1 foot, backfill 1 foot). Graded sand, such as Ottawa sand, is then introduced into the hollow-stem auger or casing to a depth of 1 foot. The porous-tube assembly with attached standpipe must then be lowered into the hole and enough additional graded sand placed into the hole to fill around the porous tube and 1 or 2 feet above it. Free water directed into the hole helps consolidate the sand around the tube. Then a bentonite pellet seal must be placed to ensure that the piezometer will measure water pressure only at the level desired.

Subsequent, or higher-level, piezometers are treated in the same manner. The sequence of backfilling and removing the auger or casing depends on the type of natural or embankment material that the hole has penetrated. The soil surrounding the hole below the casing must not be allowed to cave in.

When the piezometer hole is backfilled to within about 3 feet of the final surface, the protective cover pipe must be placed. This pipe should be surrounded by compacted clayey material either from available soil or from a mixture of bentonite with soil that produces a low permeability material. The protective cover pipe should extend 3 feet below the surface or just below the normal maximum frost line, whichever is lower.

If the casing is to be left in place, it must be lifted to an elevation such that at least half of the porous tube extends below the bottom of the casing. Obviously, a solid casing left in place precludes the installation of more than one piezometer in the hole. The placement of materials in a solid casing left in place is similar to that outlined earlier for hollow-stem auger or casing installation.

(2) *Installation in Embankments.*—Installations of porous-tube piezometers during construction of a dam should be begun when the dam foundation excavation is completed (fig. 2-40). Normally, a piezometer is placed in the foundation directly below the location where embankment piezometers will be placed. The installation of the porous-tube foundation piezometer should be completed as previously described for a borehole installation, except that a protective casing (usually 3 inches in diameter and 5 feet long) should be installed at the level of the foundation-embankment interface to protect the piezometer standpipe.

After the embankment is constructed to within 2.5 feet of the top of the casing, a coupling and a 10-foot section of casing and standpipe should be installed, and the embankment fill mounded around the outside of the casing. The casing is installed in the embankment to protect the piezometer standpipe. An air space left inside the casing allows settlement to occur in special settlement joints installed with the casing without harming the piezometer standpipe. USBR experience indicates that if a casing with settlement joints is not installed, the standpipe is likely to be damaged by embankment settlement. Air spaces inside casing have not caused any embankment problems.

During construction, foreign materials must be kept out of both the casing and the standpipe. Temporary covers should be left in place except when new lengths of standpipe and casing are added.

After the piezometer installation reaches an elevation about 5 feet below the influence zone of an embankment-level piezometer, a PVC plate with a hole for the standpipe is glued to the inside of the 3-inch riser pipe, and an 11-foot-long, 6-inch-diameter PVC pipe (influence-zone pipe) attached. This influence-zone pipe is predrilled with ½-inch-diameter holes to allow water pressure to reach the piezometer. A 5-foot-thick zone of ½-inch-diameter bentonite pellets is then placed, saturated, and compacted inside the casing above the plate and extending 2 to 2.5 feet into the 6-inch casing. The embankment piezometer is installed, and a second bentonite seal placed above the piezometer. The casing is reduced to 3 inches in diameter and extended upward to the surface or to the next piezometer location. When the installation approaches the final surface elevation, it is protected by a protective pipe assembly as described in c(4) earlier.

e. ***Monitoring Procedures.***—Water-level readings are taken with an indicator as follows:

(1) Turn on the indicator switch and switch to the BATTERY CHECK position (if available) to determine the level of charge.

(2) Check the proper operation of the unit by immersing the probe in water and noting whether the device registers a closed circuit by the voltmeter, light, or sound modes.

(3) Remove the piezometer protective pipe cap and lower the probe into the standpipe. At the level where the circuit is closed, note the length of probe wire required to reach the water level from the top of the standpipe. These data are usually recorded to an accuracy of 0.01 foot on form 7–1600 (see fig. 2-42). When there are two standpipes in a hole, each must be identifiable so that the correct data can be determined for each piezometer: The standpipe of the lower piezometer should be cut off flush with the top of the protective pipe, and the standpipe of the upper piezometer should be cut off ½ inch above the top of the protective pipe. The standpipes should also be color coded.

(4) Record the reservoir and tailwater levels at the time of observation. The elevation of the top of the standpipe should have been determined previously.

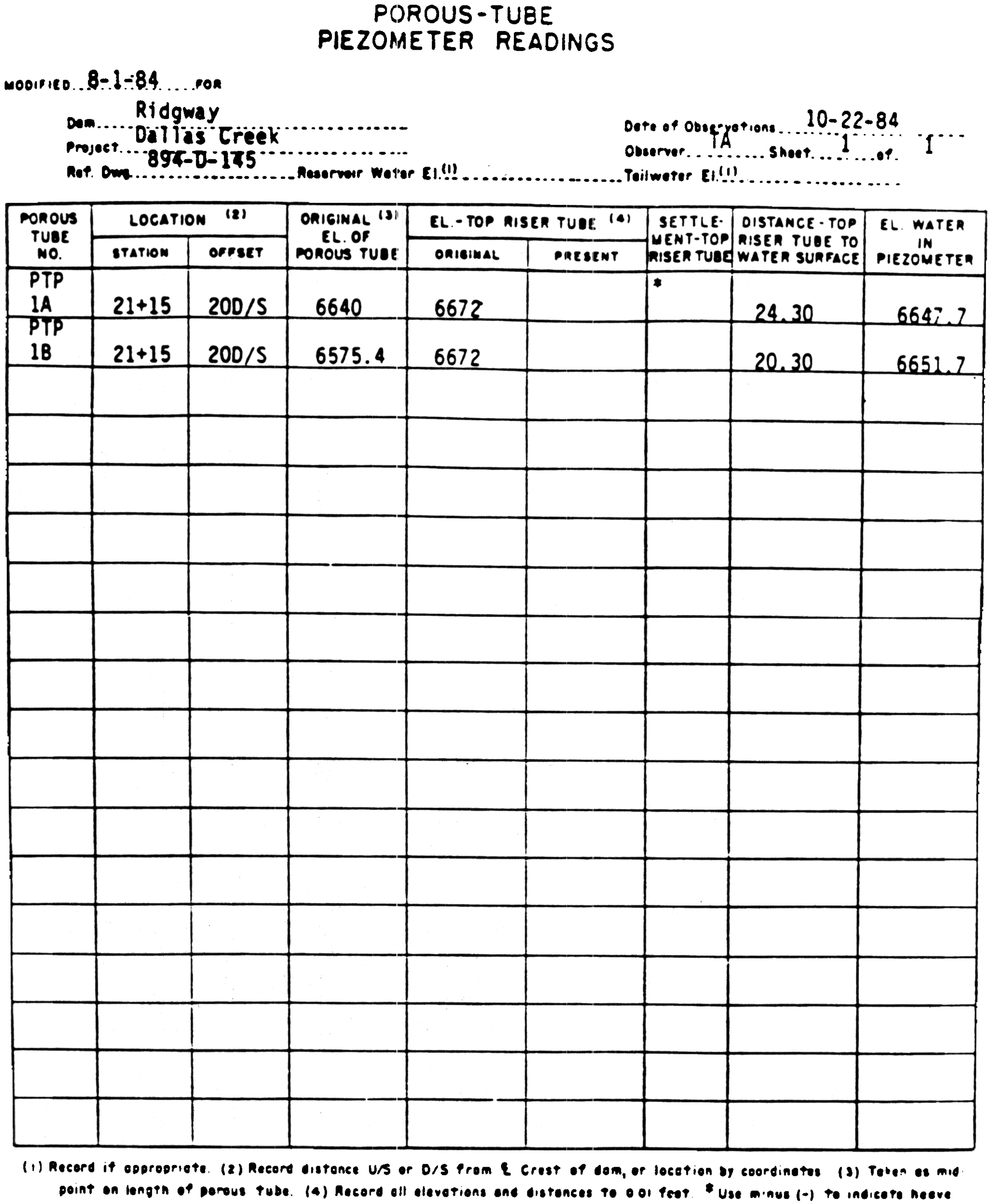
(5) Replace and lock the protective cap.

f. ***Maintenance.***—No significant maintenance is required other than cleaning the probe and replacing the batteries.

g. ***Data Processing.***—The readings are obtained in feet (or meters). The depth to water should be subtracted from the elevation of the top of the standpipe, yielding the elevation of the piezometric level. The data are transmitted to the Structural Branch, where they are processed, reviewed, and acted on as described in section 25 and on figure 1-1. An example plot of porous-tube piezometer data is shown on figure 2-43.

36. Slotted-Pipe Piezometers.—a. ***Usage.***—The SPP (slotted-pipe piezometer) measures piezometric water levels in a selected zone or zones of material in drill holes. Water passes through a slotted pipe (usually PVC) and rises in an attached standpipe. The distance from the top of the standpipe to the water level is then measured by a probe.

b. ***Advantages and Disadvantages.***—An advantage of the SPP is that length of the inlet (slotted) portion of the pipe may be varied to allow measurement of the water level across two different zones, if desired. Furthermore, SPP's can be installed in chemically impure or brackish water that might plug a porous stone. SPP devices are easy to operate, inexpensive (although drilling may be costly), very reliable, use no metallic parts, and have a long performance record.



POROUS-TUBE PIEZOMETER READINGS

MODIFIED 8-1-84 FOR

Dam Ridgway
Project Dallas Creek
Ref. Dwg. 894-D-145 Reservoir Water El.(1)

Date of Observations 10-22-84
Observer TA Sheet 1 of 1
Tailwater El.(1)

POROUS TUBE NO.	LOCATION (2)		ORIGINAL (3) EL. OF POROUS TUBE	EL.-TOP RISER TUBE (4)		SETTLEMENT-TOP RISER TUBE	DISTANCE-TOP RISER TUBE TO WATER SURFACE	EL. WATER IN PIEZOMETER
	STATION	OFFSET		ORIGINAL	PRESENT			
PTP 1A	21+15	20D/S	6640	6672		*	24.30	6647.7
PTP 1B	21+15	20D/S	6575.4	6672			20.30	6651.7

(1) Record if appropriate. (2) Record distance U/S or D/S from ℄ Crest of dam, or location by coordinates (3) Taken as mid-point on length of porous tube. (4) Record all elevations and distances to 0.01 feet. * Use minus (-) to indicate heave

Figure 2-42.—Example data sheet for porous-tube piezometer readings.

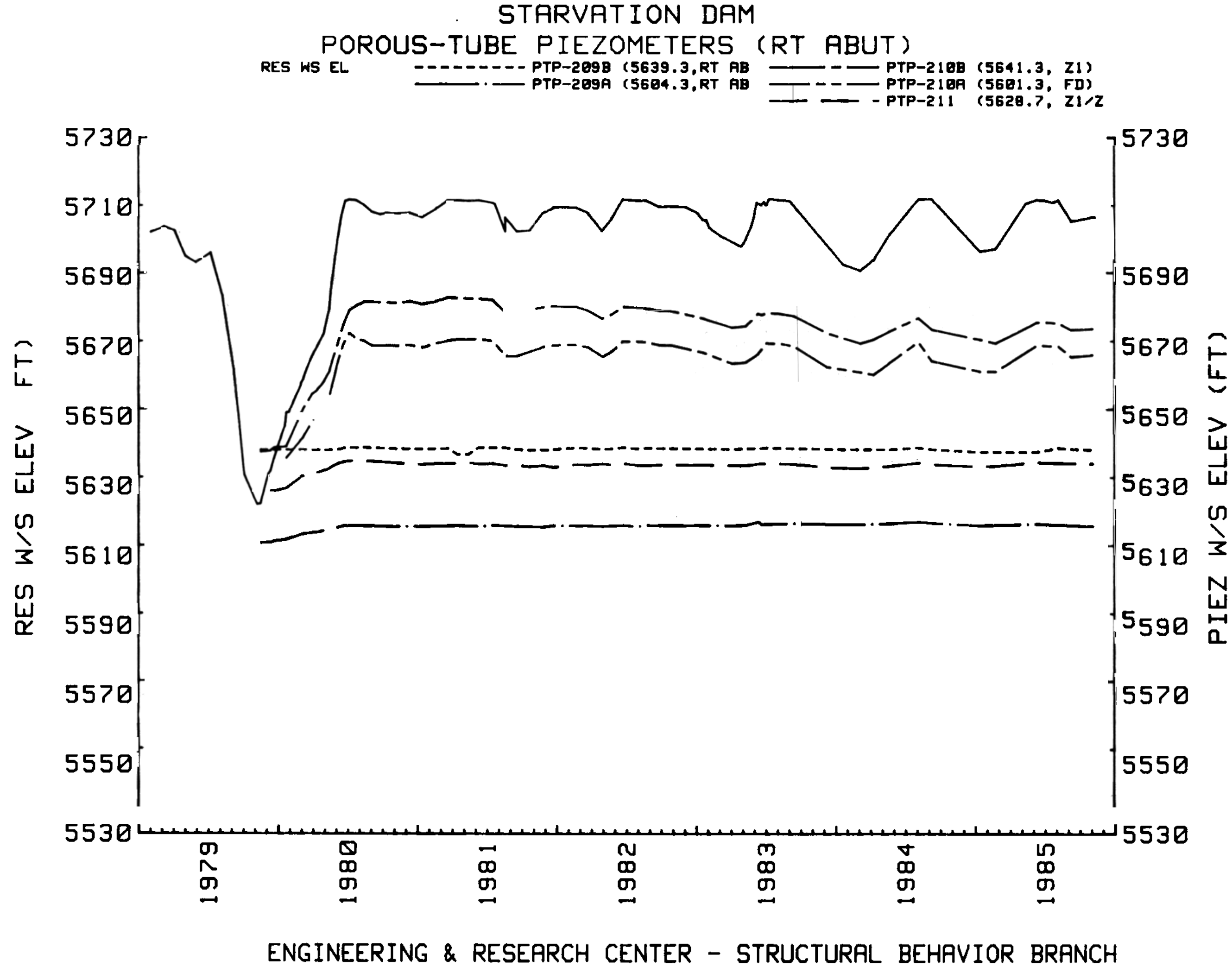


Figure 2-43.—Example plot of porous-tube piezometer data.

Disadvantages include the possible plugging of inlet slots by fine-grained materials. Thus, the use of SPP devices is normally restricted to zones of materials that do not contain fine-grained materials. In addition, the standpipe may be damaged or may cause significant interference during embankment construction operations, the standpipe must extend nearly vertically (precluding use in monitoring areas beneath the reservoir), and alterations must be made if the piezometric level is above the top of the standpipe.

c. ***Description of Equipment.***—The slotted-pipe piezometer system consists of a slotted inlet pipe, standpipe, water level indicator, protective cover pipe, and backfill material. They are generally installed as shown on figure 2-38.

(1) *Slotted Inlet Pipe.*—Slotted pipes are available in 2- to 10-foot lengths and are normally made of 1.5-inch diameter PVC pipe, as shown on figure 2-44. Normally, three rows of 0.01-inch-wide slots are cut on 120° centers around the pipe. Other pipe diameters, slot widths, and slot patterns are commercially available. For pipe lengths longer than 10 feet, pipes may be threaded together. Specification EDI-20 (app. A) describes this device.

(2) *Other Equipment.*—The standpipe, water level indicator, protective pipe cover, and backfill materials for slotted-pipe piezometers are identical to those described in section 35-c for porous-tube piezometer installations.

d. ***Installation.***—Slotted-pipe piezometers should be installed in drill holes by the method used for porous-tube piezometers described in section 35-d.

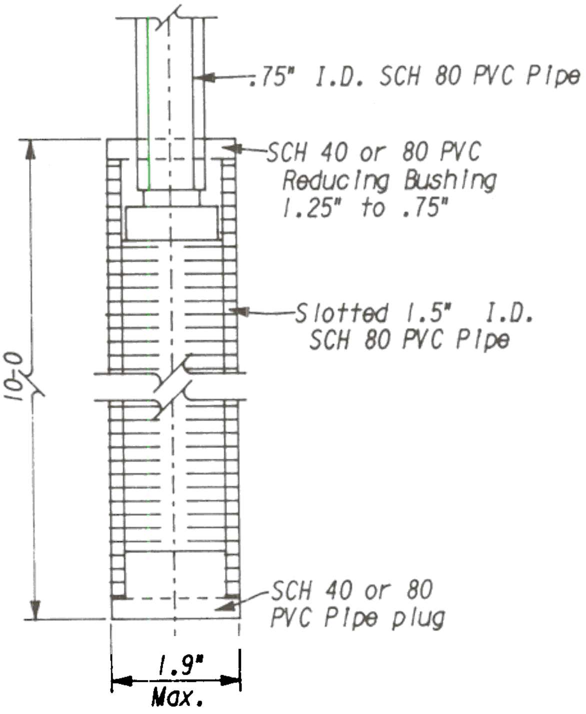


Figure 2-44.—Slotted-pipe piezometer assembly.

e. ***Monitoring Procedure.***—Slotted-pipe piezometers should be monitored using an electrical water level indicator. The step-by-step procedure is described in section 35-e.

f. ***Maintenance.***—No significant maintenance is required other than cleaning the probe and replacing the batteries.

g. ***Data Processing.***—All readings are obtained to an accuracy of 0.01 foot. The depth to water is subtracted from the elevation of the top of the standpipe to yield the elevation of the piezometric level. The data are then transmitted to the Structural Behavior Branch where they are processed, reviewed, and acted on as described in section 25 and on figure 1-1.

37. Observation Wells.—a. ***Usage.***—OW's (observation wells) are similar to slotted-pipe piezometers except that an observation well measures an average water level over a long zone in a drill hole. Observation wells allow water to pass through a slotted pipe or rise through the bottom of an open pipe. The water level measured may represent a "composite" level resulting from different zones as the various zones are not isolated by seals in the hole. Thus, an average piezometric level is measured provided that the permeabilities of the zones are quite similar. If, however, the permeabilities of the various zones are significantly different, the observation well will only reflect the water level corresponding to the zone having the greatest permeability. Observation wells may be installed in areas where the piezometric level of a certain zone is not needed, or they may be used to measure the average ground-water elevation in the abutments or downstream foundation.

b. ***Advantages and Disadvantages.***—Observation wells are simple to install and read, relatively inexpensive, and can sometimes be driven into place (such as a well point).

A particular disadvantage of observation wells is related to the occurrence of a perched water table or artesian pressure in a stratum interconnected to other strata by the drill hole. In such a case the water level represents only the average piezometric pressure throughout the depth of the well. Generally, observation wells should be installed in each aquifer so that a base reference corresponding to equilibrium conditions can be determined.

c. ***Description of Equipment.***—Observation well systems consist of an inlet pipe, standpipe, water level indicator, protective cover pipe, and backfill materials. A typical installation is shown on figure 2-38.

(1) *Inlet pipe.*—The inlet or well pipe normally consists of a 1.5-inch i.d. schedule 80 PVC pipe. The pipe is usually provided in 10-foot sections and is slotted for inlet purposes. The slots are typically sawed to a 0.010-inch width, and are spaced along the pipe length at ¼-inch centers, in three rows 120° apart around

the circumference of the pipe. The pipe sections are provided with internal threads on one end and external threads on the other end. A plug is placed in the bottom end of the pipe.

(2) *Standpipe.*—The standpipe extends from the top of the inlet pipe section to the surface at the top of the hole. Normally this pipe is also 1.5-inch i.d. PVC, but it is not slotted.

(3) *Remainder of Equipment.*—The protective cover pipe, water level indicator, and backfill materials used are the same as those described for porous-tube piezometer in section 35-c.

d. ***Installation.***—Observation wells are installed in drill holes using the method described for drill hole installation of porous-tube piezometers in section 35-d, except that a bentonite pellet seal may or may not be used.

e. ***Monitoring Procedure.***—Observation wells are monitored using the electrical water level indicator device by the procedure described in section 35-f.

f. ***Data Processing.***—All readings are obtained to an accuracy of 0.01 foot. The depth to water is subtracted from the elevation of the top of the standpipe to yield the elevation of the ground-water table. The data are then transmitted to the Structural Behavior Branch where they are processed, reviewed, and acted on as described in section 25 and on figure 1-1.

Chapter III

SEEPAGE MEASURING DEVICES

A. Currently Used Devices

38. General.—Seepage measuring devices are installed at dams to measure the amounts of seepage through, around, and under embankments. Drain outlets are commonly used as seepage measurement points. The chemical composition of seepage water is tested at many locations because changes may indicate progressive dissolution or erosion in a dam foundation or abutment.

The currently used seepage measuring devices described in this chapter include various types of weirs, Parshall flumes, trapezoidal flumes, calibrated catch containers, and flowmeters. Geophysical methods for measuring seepage are also described. A significant portion of this chapter has been excerpted from the *Water Measurement Manual* [11] published by the USBR.

39. Weirs.—a. ***General.***—Weirs are one of the oldest, simplest, and most reliable devices used to measure the flow of water. If sufficient available fall is present in the channel, and the quantity of water to be measured is not too great, the weir is a very serviceable and economical measuring device. Weirs are effective measuring devices because, for a weir of a specific size and shape, with free-flow steady-state conditions and proper weir-to-pool relationships, a specific discharge (rate of flow) exists for any specific depth of water in the upstream pool.

A submerged orifice weir, although not generally used by the USBR, is applicable where the available head is limited and the amount of floating debris is significant. However, the types of weirs most commonly used by the USBR are the 90° V-notched weir, the rectangular weir, and the trapezoidal (Cipolletti) weir. These types consist of overflow structures installed in a section of open channel.

The shape of the opening determines the name of the weir (rectangular, trapezoidal, V-notch, etc.). For a rectangular or a trapezoidal weir, the bottom edge of the opening is called the crest and the side edges are called sides or weir ends. The sheet of water leaving the weir crest is called the nappe. Weirs operate best when they discharge freely into the atmosphere. If the weir is submerged or partially submerged (tailwater is high enough to preclude free discharge into the atmosphere), nonstandard negative pressure conditions affect the rate of flow and may produce errors in flow measurements (the actual flow may be greater than that measured). In certain conditions, the under-nappe airspace is artificially ventilated to maintain near atmospheric pressure. Thus, a free-flow condition is more desirable than partially or fully submerged flow.

If the weir notch or crest is cut with a sharp upstream corner into a relatively thin plate that is mounted on a supporting bulkhead so that the flowing water does not contact the bulkhead but springs past it, the weir is called a sharp-crested weir. If the weir notch is mounted on or in a wall too thick for the water to spring past, the weir is classified as broad-crested. Although discharge tables and coefficients are available for both types, the USBR uses only the preferred sharp-crested type.

When the distances from the ends, or sides, of the weir notch to the sides of the pool above the weir are great enough to allow the water a free, unconstrained lateral approach to the crest, the water will flow uniformly and relatively slowly toward the weir ends. As the water from the sides of the channel nears the notch, it accelerates and turns to pass through the opening. Because this turning cannot occur instantaneously, a curved flow path, or contraction, results and the water springs free to form a jet narrower than the weir opening. When approach conditions from the weir pool allow complete contractions at the ends and the bottom, the weir is called a contracted weir. To have such conditions, the distance from each end of the weir to the corresponding side of the upstream pool must be at least twice the head on the weir.

If a rectangular weir is placed in a flume with the sides of the flume acting as the ends of the weir, there are no side (horizontal) contractions and the nappe does not contract from the width of the channel. This type of weir is called a suppressed weir.

The several classifications of types of weirs are simplified in USBR terminology, which is listed in parenthesis after the technical classification:

(1) Sharp-crested contracted rectangular weirs (standard contracted rectangular weirs)

(2) Sharp-crested suppressed rectangular weirs (standard suppressed rectangular weirs)
(3) Sharp-crested and sharp-sided trapezoidal weirs (standard Cipolletti weirs)
(4) Sharp-sided 90° V-notch weirs (standard 90° V-notch weirs)

On occasion, rectangular, Cipolletti, and V-notch weirs may be used in settings where contractions are not complete. These weirs are not classified as standard weirs, and standard tables and charts may not be used for discharge computations. Individual computations must be made for each situation of this kind. These computations should be based on the size, shape, and submergence condition of the weir and weir pools.

Because of greater accuracy in computations, the USBR policy is to use weirs without submergence. However, there may be occasions where it is necessary to permit submergence for limited periods.

b. *Installation.*—(1) *Standard Contracted Rectangular Weir.*—A standard contracted rectangular weir (fig. 3-1) has its crest and sides far enough from the bottom and sides (respectively) of the weir box or channel in which it is set, that full contraction is developed. This contraction is approximately the maximum that would occur with the channel boundaries at infinite distances from the crest and sides of the weir.

Extensive experiments on weirs and long USBR experience with their use dictate that the following conditions are necessary to accurately measure flow with the standard contracted rectangular weir:

(a) The upstream face of the bulkhead and the weir plate should be smooth and in a vertical plane perpendicular to the axis of the channel.

(b) The entire crest should be a level, plane surface that forms a sharp, right-angled edge where it intersects the upstream face. The thickness of the crest, measured in the direction of flow, should be between 0.03 and 0.08 inches. Both sides of a rectangular weir should be vertical and the same thickness as the crest.

(c) The upstream corners of the notch must be sharp. They should be machined or filed perpendicular to the upstream face, free of burrs or scratches, and unscratched by abrasive cloth or paper. Knife edges are not desirable and should be avoided because they are difficult to maintain and do not allow the nappe to develop properly.

(d) The downstream edges of the notch should be chamfered if the plate is thicker than the prescribed crest width. This chamfer should be at an angle of 45° or more to the surface of the crest.

(e) The distance from the bottom of the approach channel (weir pool) to the crest should preferably be at least twice the depth of water above the crest, but not less than 1 foot.

(f) The distance from the sides of the weir to the sides of the approach channel should preferably be at least twice the depth of water above the crest, but not less than 1 foot.

(g) The overflow sheet (nappe) should touch only the upstream edges of the crest and sides.

(h) The maximum downstream pool level should be at least 0.2 foot below crest elevation.

(i) The head on the weir should be taken as the difference in elevation between the crest and the water surface at a point upstream from the weir a distance of four times the maximum head on the crest.

(j) The cross-sectional area of the approach channel should be at least 8 times that of the nappe at the crest for a distance upstream from 15 to 20 times the depth of the nappe. If the approach channel is smaller than that defined by the above criteria, the velocity of approach may be too high and the staff gauge reading too low.

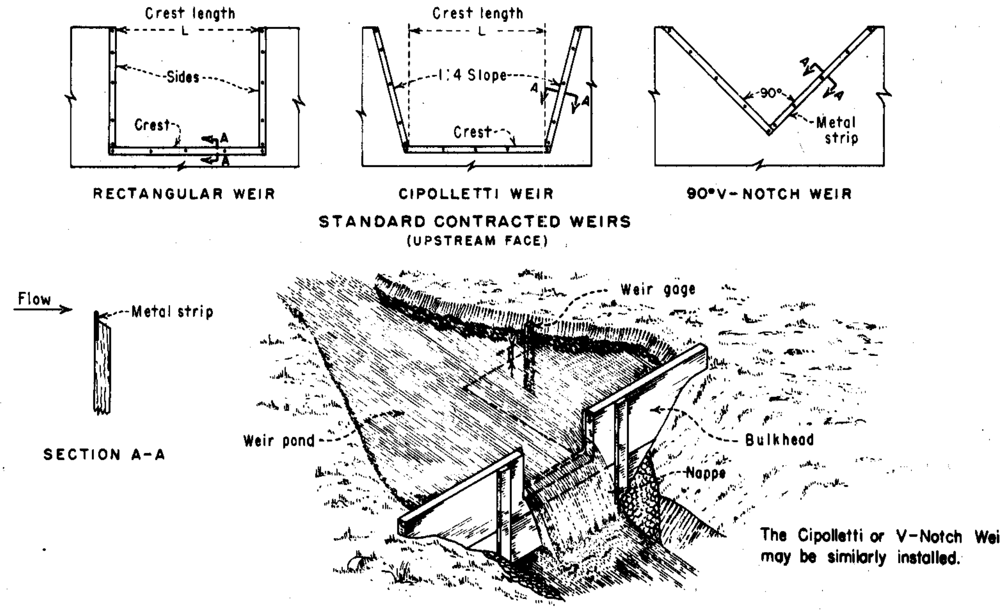
(2) *Standard Suppressed Rectangular Weir.*—An example of a typical standard suppressed rectangular weir is shown on figure 3-2. This type of weir has its crest, consisting of a thin plate, far enough from the bottom of the approach channel that full crest contraction is developed. However, because the sides of the weir coincide with the sides of the approach channel, no lateral contraction is possible.

The conditions for accurate measurements with the standard suppressed rectangular weir are identical with those of the standard contracted rectangular weir, except those relating to side contraction. In the suppressed weir, the sides of the approach channel should coincide with the sides of the weir and should extend downstream beyond the crest to prevent lateral expansion of the nappe.

Special care must be taken with suppressed weirs to secure proper aeration beneath the nappe at the crest. This is usually accomplished by placing vents on both sides of the weir box under the nappe.

(3) *Standard Cipolletti (Trapezoidal) Weir.*—In a standard Cipolletti weir (fig. 3-1), its crest and sides, which are thin plates, are far enough from the bottom and sides, respectively, of the approach channel so that full contraction of the nappe occurs. The sides of the weir incline outward at a slope of one horizontal to four vertical.

The Cipolletti weir is a contracted weir, and should be installed accordingly. However, its discharge occurs essentially as though its end contractions were suppressed because the contractions are compensated for by the outward slope of the weir sides.



The Cipolletti or V-Notch Weirs may be similarly installed.

Figure 3-1.—Standard contracted weir installation. 103-D-858.

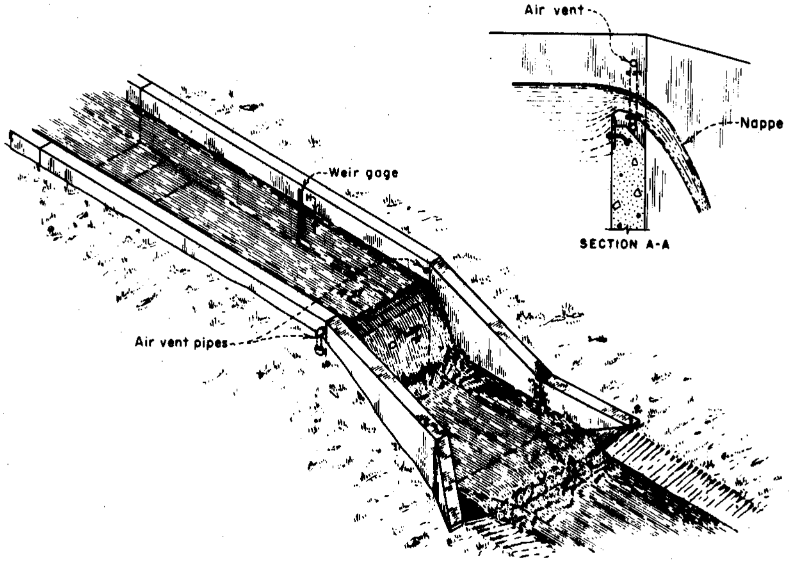


Figure 3-2.—Standard suppressed rectangular weir. 103-D-854.

All conditions for accurate measurements stated for the standard contracted rectangular weir apply to the Cipolletti weir. The weir should not be used for heads less than about 0.2 foot nor for heads greater than one-third the crest length.

(4) *Standard 90° V-Notch Weir.*—The triangular or V-notch thin plate weir is an accurate flow measuring device particularly suited for small flows. The V-notch normally used by the USBR is the 90° V-notch shown on figure 3-1. The 45° and the 22.5° V-notch weirs are also used.

The crest of the standard 90° V-notch weir consists of a thin plate set on the sides of the notch which are inclined 45° from the vertical. This weir operates as a contracted weir, and all conditions for accuracy stated for the standard contracted rectangular weir apply. The distance from the sides of the weir (measured from the point of the maximum water surface) to the sides of the channel should be at least twice the head on the weir. The minimum distances from the crest to the pool bottom should be measured from the vertex of the notch to the channel floor.

Because the V-notch weir has no crest length, the head required for a small flow through it is greater than that required with the other types of weirs. This is an advantage for small discharges because the nappe will spring free of the crest; whereas, it would cling to the crest of another type of weir and make the measurement worthless. Although Cipolletti and rectangular weirs with crests about 6 inches long are sometimes used for measuring small flows, they are not as accurate or as sensitive for such flows as V-notch weirs and are not recommended where the V-notch weir can be used. The 45° and 22.5° weirs are more accurate for smaller flows than the 90° V-notch weirs.

c. ***Selection of Weir Type.***—Each of the weirs used by the USBR has characteristics that make it suitable for particular operating conditions. In general, a rectangular suppressed weir or a 90° V-notch weir provides the most accurate measurements. Cipolletti weirs and contracted rectangular weirs have end contractions and have not been investigated experimentally as thoroughly as the suppressed rectangular and V-notch weirs. They are, however, useful for many applications.

Usually, the range of flows to be measured by a weir can be fairly well estimated in advance. With this range in mind, the following points should be considered:

- The minimum head should be at least 0.2 foot to prevent the nappe from clinging to the crest, and because at smaller depths it is difficult to get sufficiently accurate gauge readings to calculate reliable flow quantities.
- The length of rectangular and Cipolletti weirs should be at least three times the head.
- The 90° V-notch weir is the preferred type for measuring discharges less than 1 ft^3/s (second-foot). It is as accurate as the other types of weirs for flows from 1 to 10 ft^3/s. Thus, it is well suited for discharges up to and a little beyond 10 ft^3/s if sufficient head is available. For flows less than 0.5 ft^3/s, a 45° or 22.5° V-notch weir is preferred.
- If possible, the crests should be placed high enough so the water flowing over them will fall freely, leaving an airspace under and around the sides of the nappe. If submergence is permitted, special computations and reduced flow measuring accuracy should be expected.

d. ***Discharge Measurements.***—The rate of flow or discharge in cubic feet per second over the crest of a standard contracted rectangular weir or a standard Cipolletti weir is determined by the head, H, in feet and by the crest length, L, in feet. The discharge of the standard 90° V-notch weir is determined directly by the head on the bottom of the V-notch.

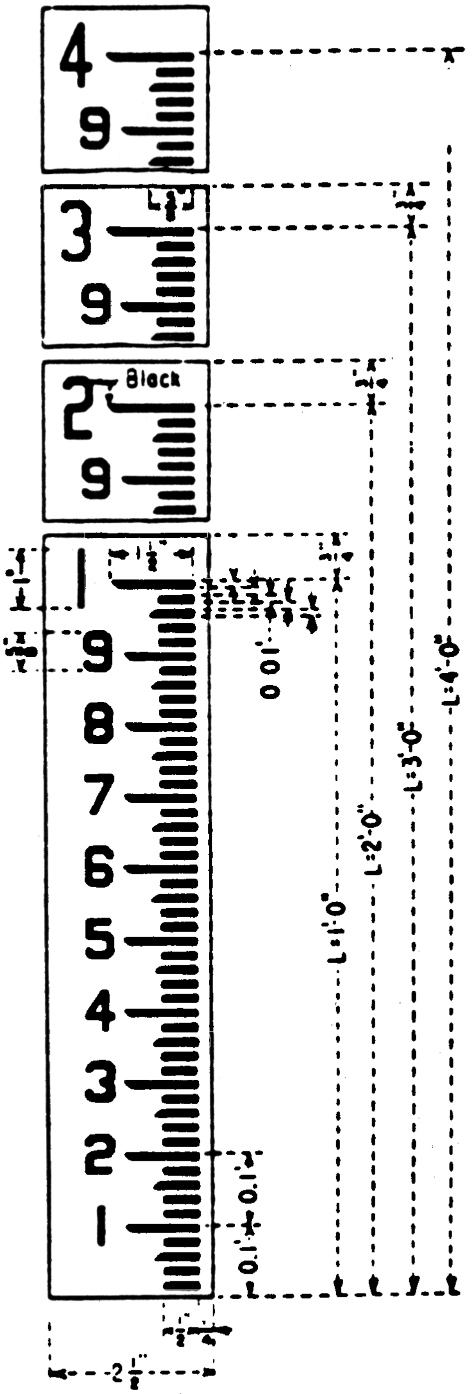
As a stream passes over a weir, the top surface of the water curves downward. This curved surface, or drawdown, extends upstream a short distance from the weir notch. The head, H, must be measured at a point in the weir pool upstream of the drawdown. The distance upstream should be at least four times the maximum head on the weir, and the same gauge point should be used for lesser discharges. A staff gauge having a graduated scale with the zero placed at the same elevation at the weir crest is usually acceptable for the head measurements. Figure 3-3 illustrates a standard staff gauge adopted by the USBR.

When a simple weir is placed across a channel, a flat-top stake or post may be driven into the bed of the weir pool until its top is at the same elevation as the crest of the weir. The depth of the water over this post will be the head on the crest. The post should be placed upstream of the drawdown (a distance assumed to be four times the maximum weir head) and close enough to the bank of the channel to be reached easily.

After the head is determined, the rate of flow, or discharge, may be found by referring to the tables described in succeeding paragraphs. These tables are for free-flow conditions and are applicable only to weirs installed in accordance with the requirements for standard contracted weirs stated in the preceding paragraphs. Many of the values shown in these tables were determined experimentally. The remainder were computed from the accepted formulas discussed later. Table 3-1 gives the maximum and minimum discharge capacities of some standard weirs.

e. ***Discharge Formulas.***—(1) *Standard Contracted Rectangular Weirs.*—Two widely used formulas for computing the discharges over standard contracted rectangular weirs are those of Hamilton Smith and J. B. Francis. The formulas proposed by Hamilton Smith require the use of coefficients of discharge varying with the head of water on the weir and with the length of the weir. Consequently, the Smith formulas are somewhat inconvenient to use, although they are accurate for the ranges of coefficients usually given. The Francis formula for a standard contracted rectangular weir, operating under favorable conditions as prescribed in previous paragraphs and neglecting velocity of approach, is:

$$Q = 3.33\, H^{3/2} (L - 0.2H) \tag{1}$$



NOTES

Material of 18 gage (U.S. Standard) metal coated with substantial thickness of porcelain enamel. Face of gage is white. Numerals and graduations are black. Graduations are sharp and accurate to dimensions shown.

Length "L" represents gage limits.

Gages may be made in any length desired using similar details.

Figure 3-3.—Standard staff gauge. 103-D-855.

where:

Q = discharge in cubic feet per second neglecting velocity of approach,
L = length of the weir, in feet, and
H = head on the weir, in feet.

Table 3-2 provides values of $H^{3/2}$ for convenience in computing discharge with formula (1).

Table 3-1—Maximum and minimum capacities of standard weirs, in cubic feet per second.

Length, feet	Contracted rectangular		Suppressed rectangular		Cipolletti	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
1.0	0.590	0.286	0.631	0.298	0.638	0.301
1.5	1.65	.435	1.77	.447	1.79	.452
2.0	3.34	.584	3.65	.596	3.69	.602
2.5	5.87	.732	6.30	.744	6.37	.753
3.0	9.32	.881	10.0	.893	10.1	.903
3.5	13.8	1.03	14.8	1.04	15.0	1.05
4.0	19.1	1.18	20.4	1.19	20.6	1.20
4.5	25.7	1.33	27.5	1.34	27.8	1.35
5.0	33.5	1.48	36.0	1.49	36.4	1.51
5.5	42.3	1.63	45.3	1.64	45.8	1.66
6.0	52.7	1.78	56.6	1.79	57.2	1.81
7.0	77.4	2.07	82.9	2.08	83.8	2.11
8.0	108.5	2.37	116.2	2.38	117.5	2.41
9.0	145.3	2.67	155.9	2.68	157.6	2.71
10.0	188.8	2.97	202.4	2.98	204.6	3.01
12.0	298.4	3.56	320.0	3.57	323.6	3.61
14.0	439.1	4.16	470.4	4.17	475.6	4.21
16.0	612.0	4.75	656.5	4.76	663.8	4.82
18.0	822.4	5.35	882.0	5.36	891.8	5.42

NOTE—Limits follow the prescribed practice of $h>0.2$ foot and $h<\frac{1}{3}L$.

The velocity of approach is normally neglected in the computations because USBR weirs are commonly installed and maintained in a manner that makes the velocity of approach a negligible factor.

The Francis formula (1) contains a constant discharge coefficient, which facilitates the computations without the use of tables. Because the Francis experiments were made on comparatively large weirs, most having a 10-foot crest and heads ranging from 0.4 to 1.6 feet; therefore, formula (1) applies more to weirs of this size than to short weirs with low heads. However, USBR experiments on 6-inch, 1-foot, and 3-foot weirs show that formula (1) also applies fairly well to shorter weirs, provided the head of water on the weir is not greater than about one-third the length of the weir. For a head to length ratio greater than one-third, the actual discharges exceed those given by formula (1) by an amount that increases gradually from 0 percent, for a ratio of 1 to 3, to about 30 percent, for a ratio of 1 to 1.

An improved formula for computing discharges for contracted rectangular, thin-plate weirs has been developed by Kindsvater and Carter. The formula is simple, comprehensive, accurate, and is recommended for general use. It applies to both suppressed and unsuppressed free-discharge weirs. Direct, accurate, simple computations quickly yield the rate of flow with correction factors for approach velocity and approach channel depth and width included. The basic Kindsvater-Carter equation, is:

$$Q = C_e L_e (H_e)^{3/2} \tag{2}$$

where:

C_e = a discharge coefficient,
$L_e = L+K_b$, and
$H_e = H+0.003$ (for English units).

In these relationships:
Q = discharge, in cubic feet per second,
H = head above the weir crest, in feet,

Table 3-2.—Three-halves powers of numbers for use in determining $H^{3/2}$.

Number (H)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.0000	0.0010	0.0028	0.0052	0.0080	0.0112	0.0147	0.0185	0.0226	0.0270
	.0316	.0355	.0416	.0469	.0524	.0581	.0640	.0701	.0764	.0828
.2	.0894	.0962	.1032	.1103	.1176	.1250	.1326	.1403	.1482	.1562
.3	.1643	.1726	.1810	.1896	.1983	.2071	.2160	.2251	.2342	.2436
.4	.2530	.2625	.2722	.2820	.2919	.3019	.3120	.3222	.3325	.3430
.5	.3536	.3642	.3750	.3858	.3968	.4079	.4191	.4303	.4417	.4532
.6	.4648	.4764	.4882	.5000	.5120	.5240	.5362	.5484	.5607	.5732
.7	.5857	.5983	.6109	.6237	.6366	.6495	.6626	.6757	.6889	.7022
.8	.7155	.7290	.7425	.7562	.7699	.7837	.7975	.8115	.8255	.8396
.9	.8538	.8681	.8824	.8969	.9144	.9259	.9406	.9553	.9702	.9850
1.0	1.000	1.015	1.030	1.045	1.061	1.076	1.091	1.107	1.122	1.138
1.1	1.154	1.170	1.185	1.201	1.217	1.233	1.249	1.266	1.282	1.298
1.2	1.314	1.331	1.348	1.364	1.381	1.398	1.414	1.431	1.448	1.465
1.3	1.482	1.499	1.517	1.534	1.551	1.569	1.586	1.604	1.621	1.639
1.4	1.657	1.674	1.692	1.710	1.728	1.746	1.764	1.782	1.801	1.819
1.5	1.837	1.856	1.874	1.892	1.911	1.930	1.948	1.967	1.986	2.005
1.6	2.024	2.043	2.062	2.081	2.100	2.120	2.139	2.158	2.178	2.197
1.7	2.216	2.236	2.256	2.276	2.295	2.315	2.335	2.355	2.375	2.395
1.8	2.415	2.435	2.455	2.476	2.496	2.516	2.537	2.557	2.578	2.598
1.9	2.619	2.640	2.660	2.681	2.702	2.723	2.744	2.765	2.786	2.807
2.0	2.828	2.850	2.871	2.892	2.914	2.935	2.957	2.978	3.000	3.022
2.1	3.043	3.065	3.087	3.109	3.131	3.153	3.174	3.197	3.219	3.241
2.2	3.263	3.285	3.308	3.330	3.352	3.375	3.398	3.420	3.443	3.465
2.3	3.488	3.511	3.534	3.557	3.580	3.602	3.626	3.649	3.672	3.695
2.4	3.718	3.741	3.765	3.788	3.811	3.835	3.858	3.882	3.906	3.929
2.5	3.953	3.977	4.000	4.024	4.048	4.072	4.096	4.120	4.144	4.168
2.6	4.192	4.217	4.241	4.265	4.290	4.314	4.338	4.363	4.387	4.412
2.7	4.437	4.461	4.486	4.511	4.536	4.560	4.585	4.610	4.635	4.660
2.8	4.685	4.710	4.736	4.761	4.786	4.811	4.837	4.862	4.888	4.913
2.9	4.938	4.964	4.990	5.015	5.041	5.067	5.093	5.118	5.144	5.170
3.0	5.196	5.222	5.248	5.274	5.300	5.327	5.353	5.379	5.405	5.432
3.1	5.458	5.484	5.511	5.538	5.564	5.591	5.617	5.644	5.671	5.698
3.2	5.724	5.751	5.778	5.805	5.832	5.859	5.886	5.913	5.940	5.968
3.3	5.995	6.022	6.049	6.077	6.104	6.132	6.159	6.186	6.214	6.242
3.4	6.269	6.297	6.325	6.352	6.380	6.408	6.436	6.464	6.492	6.520
3.5	6.548	6.576	6.604	6.632	6.660	6.689	6.717	6.745	6.774	6.802
3.6	6.830	6.859	6.888	6.916	6.945	6.973	7.002	7.031	7.060	7.088
3.7	7.117	7.146	7.175	7.204	7.233	7.262	7.291	7.320	7.349	7.378
3.8	7.408	7.437	7.466	7.496	7.525	7.554	7.584	7.613	7.643	7.672
3.9	7.702	7.732	7.761	7.791	7.821	7.850	7.880	7.910	7.940	7.970
4.0	8.000	8.030	8.060	8.090	8.120	8.150	8.181	8.211	8.241	8.272
4.1	8.302	8.332	8.363	8.393	8.424	8.454	8.485	8.515	8.546	8.577
4.2	8.607	8.638	8.669	8.700	8.731	8.762	8.793	8.824	8.855	8.886
4.3	8.917	8.948	8.979	9.010	9.041	9.073	9.104	9.135	9.167	9.198
4.4	9.230	9.261	9.292	9.324	9.356	9.387	9.419	9.451	9.482	9.514
4.5	9.546	9.578	9.610	9.642	9.674	9.706	9.738	9.770	9.802	9.834
4.6	9.886	9.898	9.930	9.963	9.995	10.03	10.06	10.09	10.12	10.16

Table 3-2.—Three-halves powers of numbers for use in determining $H^{3/2}$.—Continued.

Number (H)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
4.7	10.19	10.22	10.25	10.29	10.32	10.35	10.39	10.42	10.45	10.48
4.8	10.52	10.55	10.58	10.62	10.65	10.68	10.71	10.75	10.78	10.81
4.9	10.85	10.88	10.91	10.95	10.98	11.01	11.05	11.08	11.11	11.15
5.0	11.18	11.21	11.25	11.28	11.31	11.35	11.38	11.42	11.45	11.48
5.1	11.52	11.55	11.59	11.62	11.65	11.69	11.72	11.76	11.79	11.82
5.2	11.86	11.89	11.93	11.96	11.99	12.03	12.06	12.10	12.13	12.17
5.3	12.20	12.24	12.27	12.31	12.34	12.37	12.41	12.44	12.48	12.51
5.4	12.55	12.58	12.62	12.65	12.69	12.72	12.76	12.79	12.83	12.86
5.5	12.90	12.93	12.97	13.00	13.04	13.07	13.11	13.15	13.18	13.22
5.6	13.25	13.29	13.32	13.36	13.39	13.43	13.47	13.50	13.54	13.57
5.7	13.61	13.64	13.68	13.72	13.75	13.79	13.82	13.86	13.90	13.93
5.8	13.97	14.00	14.04	14.08	14.11	14.15	14.19	14.22	14.26	14.29
5.9	14.33	14.37	14.40	14.44	14.48	14.51	14.55	14.59	14.62	14.66
6.0	14.70	14.73	14.77	14.81	14.84	14.88	14.92	14.95	14.99	15.03
6.1	15.07	15.10	15.14	15.18	15.21	15.25	15.29	15.33	15.36	15.40
6.2	15.44	15.48	15.51	15.55	15.59	15.62	15.66	15.70	15.74	15.78
6.3	15.81	15.85	15.89	15.93	15.96	16.00	16.04	16.08	16.12	16.15
6.4	16.19	16.23	16.27	16.30	16.34	16.38	16.42	16.46	16.50	16.53

L = length of the weir crest, in feet,
B = width of the approach channel, in feet,
P = vertical distance from the weir crest to the approach pool invert, in feet,
k_b = a correction factor used to obtain the effective weir length, L_e, and
k_h = a constant correction factor (0.003 foot) used to obtain the effective weir head, H_e.

The factor K_b changes with different ratios of notch or crest length, L, to width of approach channel, B. Values of K_b for ratios of L/B from 0 to 1 are shown on figure 3-4. The factor K_h is a constant value equal to 0.003 foot.

The effective discharge coefficient, C_e, includes the effects of the relative depth and the relative width of the approach channel. Thus, C_e is a function of H/P and L/B, and values of C_e can be obtained from the curves on figure 3-5.

For the limiting case of a fully suppressed rectangular weir where no side contractions occur, $C_e = 3.22+0.40\ H/P$ (for English units). Solution of this equation for heads not more than one-fourth the distance from crest to pool invert, or $H/P = 0.25$, gives a discharge coefficient of about 3.32. This closely corresponds to that of the Francis equation. For larger head ratios where velocity of approach becomes important, C_e increases.

Similarly, in weirs not fully suppressed, C_e is a function of crest length to pool width ratio, L/B. Figure 3-5 shows that C_e increases progressively less rapidly at higher head ratios as the effects of greater and greater side contractions (progressively smaller L/B ratios are encountered.

The Kindsvater-Carter method of determining discharges for rectangular weirs makes it well suited for USBR use. The formula has not yet been incorporated into the tables in the *Water Measurement Manual* [11]. It is particularly useful for installations where full crest contractions or full end contractions are difficult to achieve.

The Kindsvater-Carter method should be used for determining discharges in all cases where rectangular thin-plate weir installations do not have pool depths at least twice the head on the weir and where contracted weirs do not have distances from weir ends to pool banks at least twice the head.

The Kindsvater-Carter formula [eq (2)] does not apply to either the V-notch or Cipolletti (trapezoidal) weirs, but these weirs should not be used unless the prescribed contractions are available.

Table 8 in the *Water Measurement Manual* [11] on (pp. 245-259) shows the discharges in second-feet (cubic feet per second) for standard contracted rectangular weirs, neglecting the velocity of approach. These discharges were computed by the Francis formula, equation (1), for the lengths and heads ordinarily used in

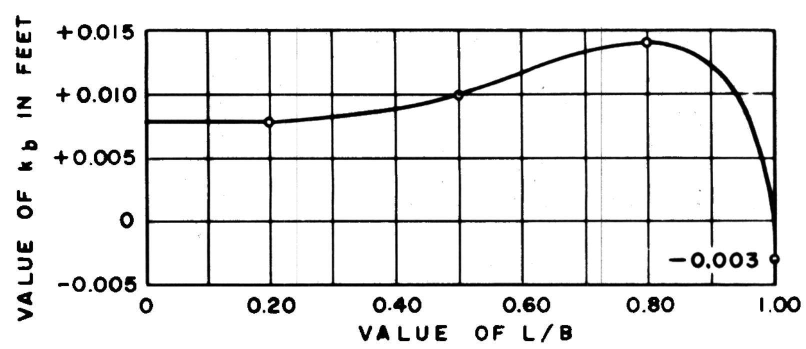


Figure 3-4.—Width-adjustment factors, k_b, for $0 \leq L/B \leq 1$ 103-D-856

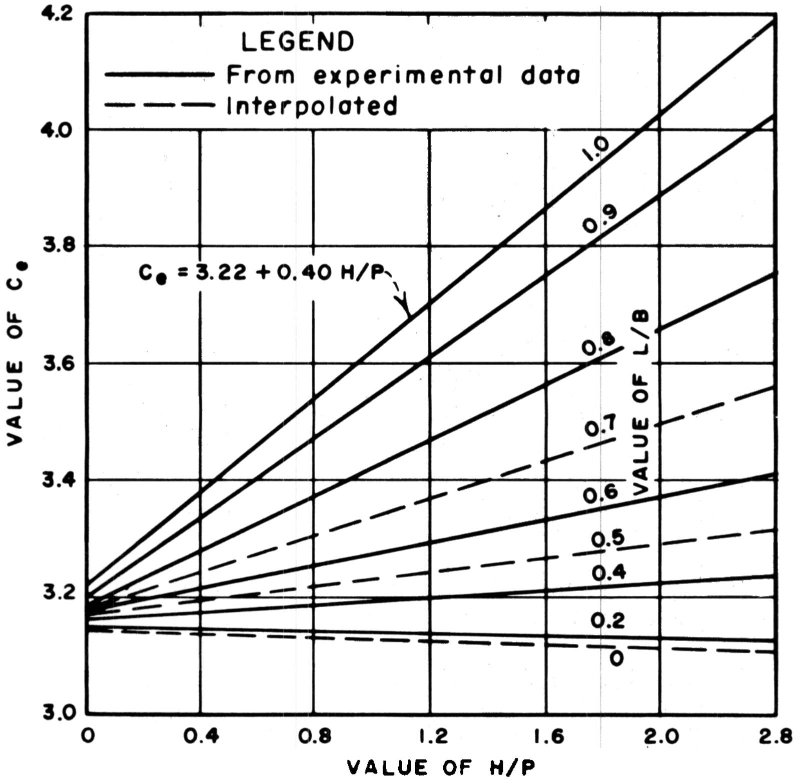


Figure 3-5.—Discharge coefficients for all values of the contraction ratio, L/B. 103-D-857

measuring small quantities of irrigation water; except that for 6-inch, 1-foot, 2-foot, and 3-foot weirs with heads greater than one-third the crest length, USBR experimental values have been inserted instead of the values computed by the formula.

The discharges in table 8 of [11] may be considered fairly accurate for weirs of the above lengths and for weirs of other lengths where the head does not exceed one-third the length of the weir crest.

(2) *Standard Suppressed Rectangular Weirs.* The two principal formulas used for computing the discharge of the standard suppressed rectangular weir were also proposed by Smith and Francis. In the Smith formulas for suppressed weirs, as for contracted weirs, coefficients of discharge vary with the head on the weir and with the length of the weir; therefore, these formulas are not convenient for use in computations without tables of coefficients. The law of these variations for the two types of weirs is different, so a separate table is provided for each.

The Francis formula for a standard suppressed rectangular weir, neglecting velocity of approach, is:

$$Q = 3.33\ L(H)^{3/2} \text{ (for English units)} \tag{3}$$

In this formula, the symbols have the same significance as in the formula for contracted rectangular weirs discussed in (1) above. The coefficient of discharge was obtained by Francis from the same general set of experiments stated for the contracted rectangular weir. No extensive tests have yet been made to determine the applicability of these formulas to weirs less than 4 feet long. Discharge tables give discharges for heads as low as 0.01 foot. However, as a practical matter, heads less than 0.20 foot should not be used under ordinary field conditions, because the nappe may not spring free of the crest.

The Kindsvater-Carter formula, equation (2), previously discussed is ideally suited for use with suppressed rectangular weirs. Because of its simplicity and accuracy, this formula is expected to attain widespread use.

Table 9 in the *Water Measurement Manual* (pp. 260-262) shows the discharges in cubic feet per second for standard suppressed rectangular weirs, neglecting the velocity of approach. The discharges were computed by the Francis formula, equation (1), for lengths and heads commonly used in measuring small quantities of water. The table is provided for ready determination of discharge from field data. It is reasonably accurate for small and moderate heads. Only in unusual circumstances is it necessary to use the formulas.

(3) *Standard Cipolletti Weirs.*—The Cipolletti weir is, by definition, a contracted weir and must be installed as such to obtain reasonably correct and consistent discharge measurements. However, the Cipolletti formula provides for the reduced discharge caused by end contractions. This is accomplished by sloping the sides of the weir sufficiently to overcome the effect of contraction.

The Cipolletti formula, in which the Francis coefficient is increased by about 1 percent, neglecting velocity of approach, is:

$$Q = 3.367\ L(H)^{3/2} \tag{4}$$

where:

Q = discharge, in cubic feet per second,
L = length of the weir crest, in feet, and
H = head on the weir crest, in feet.

Although measurements obtained by the use of Cipolletti weirs and the above formula are inherently not as accurate as those obtainable with suppressed rectangular or V-notch weirs, they are acceptable when great precision is not required.

Table 10 in the *Water Measurement Manual* (pp. 263-269) shows discharges in cubic feet per second for standard Cipolletti weirs, neglecting the velocity of approach, for heads and lengths of weirs generally used in measuring small quantities of irrigation water. For the 6-inch, 1-foot, and 3-foot weirs, and for heads greater than one-third the crest length, the discharges have been taken from USBR experiments. All other discharges were computed from the Cipolletti formula, equation (4). The data may be considered accurate enough for general use for weirs of these lengths for all heads given in the table, and for weirs of other lengths for heads not larger than one-third the crest length.

(4) *Standard 90° V-Notch Weirs.*—Several well-known formulas are used to compute the discharge over 90° V-notch weirs. The most commonly used are the Cone formula and the Thomson formula.

The Cone formula, considered by authorities to be the most reliable for small weirs and for conditions generally encountered, is:

$$Q = 2.49\ (H)^{2.48} \tag{5}$$

where:

Q = discharge over the weir, in cubic feet per second, and
H = head on the weir crest, in feet.

Ordinarily, V-notch weirs are not appreciably affected by the velocity of approach. If the weir is installed with complete contraction, the velocity of approach will be low.

Table 3-3 contains discharges in cubic feet per second for the standard 90° contracted V-notch weir, neglecting velocity of approach, computed from the Cone formula, equation (5), for a range of heads ordinarily used in measuring small flows.

f. ***Maintenance.***—For best operating conditions, the weir structure should be set in a straight reach of the channel, perpendicular to the line of flow. The weir crest must be level and the bulkhead plumb. Adequate cutoff walls well tamped in place should be used on the weir structure to prevent undermining or washing by erosion around it. The banks and bottom of the channel should be trimmed to conform approximately to the shape and size of the box for 10 to 20 feet upstream for small structures, and 50 to 70 feet or more for larger structures.

A weir box may accumulate sand and silt to such an extent that discharge measurements will be considerably in error. For sluicing silt and sand deposits, an opening may be provided in the weir bulkhead at the floor line beneath the weir notch. This sluiceway should be provided with a suitable cover to prevent leakage. Frequent trimming of the channel and cleaning of the weir box structure with a shovel or scraper may be necessary to maintain proper operating conditions. Carefully selecting and building an accurate weir station does little good if it is then permitted to fill with sediment, and the approach channel is allowed to deteriorate. Such neglect can only result in erroneous discharge determinations.

The weir and weir pool should be freed of weeds and trash on each visit and the weir pool should be cleaned of sediment as it accumulates. The weir pool banks should be trimmed to maintain the minimum distance from the notch: twice the maximum weir head. And the bottom of the pool must be kept low enough to maintain the minimum distance from the crest: twice the maximum head on the weir.

The level of the crest should be checked periodically and compared with the elevation of the zero reading on the staff gauge. Inspections should be made to determine whether there is leakage around the weir. If such leakage occurs, the structure should be repaired immediately and carefully rechecked to ensure that the weir is level and at the same elevation as the zero reading on the staff gauge.

Great care must be taken to avoid damaging the weir notch itself. Even small nicks and dents can reduce the accuracy of an otherwise effective weir installation. Any nicks or dents that do occur should be carefully dressed with a fine-cut file or stone, stroking only in the plane of the weir upstream face, the plane of the weir crest or sides, or the plane of the chamfers. Under no circumstances should the upstream corners of the notch be rounded or chamfered. Nor should any attempt to remove an imperfection change the shape of the weir opening. Only those portions of the metal that protrude above the normal surface should be removed.

g. ***Data Processing and Review.***—Field data consisting of flow quantities or head measurements are entered on field data forms as shown on figure 3-6. The data are transmitted to the Structural Behavior Branch in units of either gallons per minute or cubic feet per second. Upon arrival, the data are processed and reviewed as described in section 25. Many of the calculations are now performed automatically by the computer program used in the Structural Behavior Branch. Data plots are then prepared as shown on figure 3-7.

40. Parshall Flumes.—a. ***General.***—A Parshall flume is a specially shaped open channel flow section that may be installed in a drainage lateral or ditch to measure the rate of flow of water. A typical Parshall flume (shown on fig. 3-8) has four significant advantages: (1) it can operate with a relatively small head loss, (2) it is relatively insensitive to the velocity of approach, (3) it has the capability of yielding accurate measurements with no submergence, moderate submergence, or even with considerable submergence downstream, and (4) its velocity of flow is sufficiently high to virtually eliminate sediment deposition within the structure during operation. The Parshall flume is a particular form of venturi flume and is named for its principal developer, Ralph L. Parshall.

The constricted throat of the flume produces a differential head that can be related to discharge. The downward sloping floor immediately downstream of the crest gives the Parshall flume its ability to withstand relatively high degrees of submergence without affecting the rate of flow. The converging upstream portion of the flume accelerates the entering flow, essentially preventing the deposition of sediment that would reduce measurement accuracy. The velocity of approach, which can have an adverse effect on the operation of weirs and orifices if too high, is usually small and has little effect on the rate of discharge of the Parshall flume. However, the approaching flow should be well distributed across the channel and relatively free of turbulence, eddies, and waves if accurate measurements are expected.

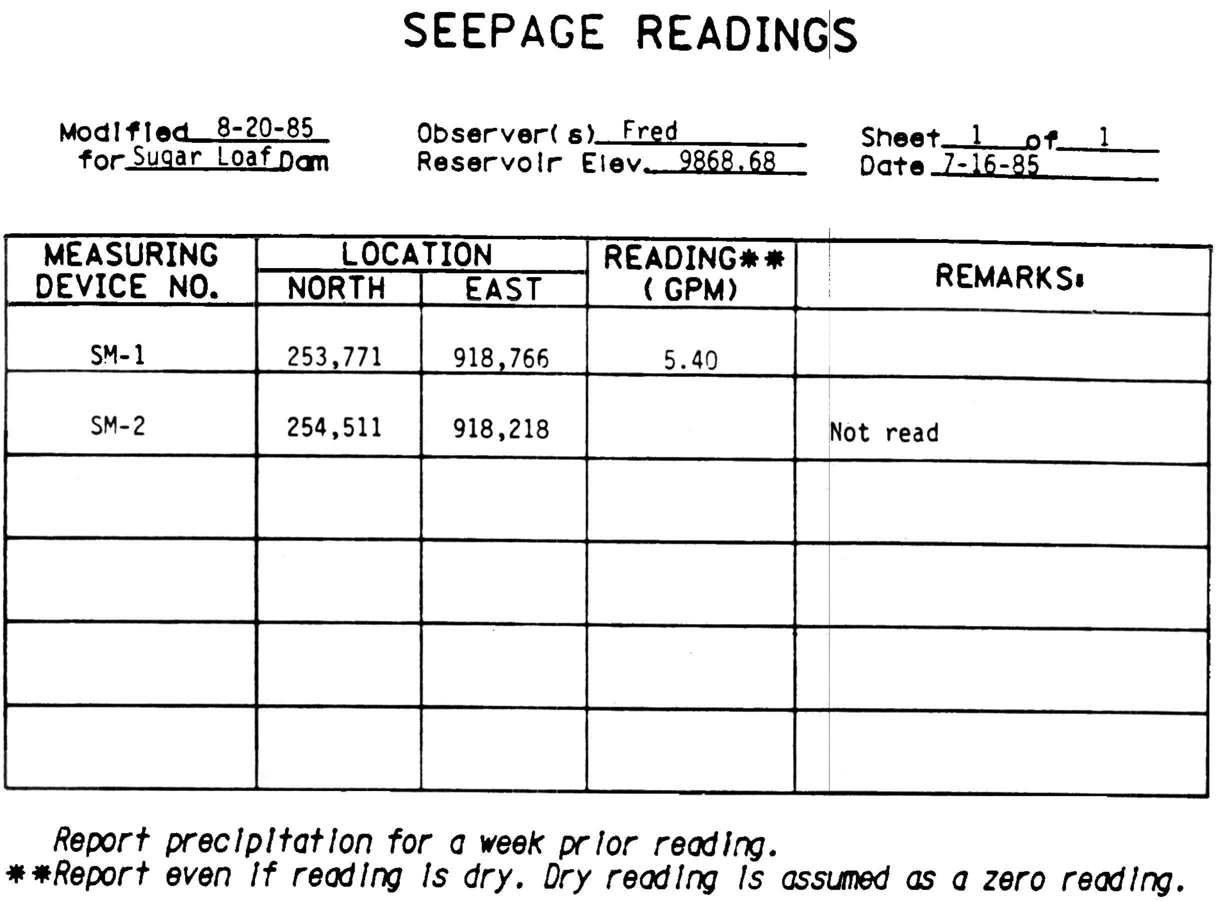
Discharge through a Parshall flume can occur for two conditions of flow. The first, free flow, occurs when there is insufficient backwater depth to reduce the discharge rate. The second, submerged flow, occurs when

Table 3-3.—Discharge of 90° V-notch weirs. Computed from the Cone formula, $Q = 2.49H^{2.48}$.

Head, ft	Discharge, ft³/s	Head, ft	Discharge, ft³/s	Head, ft	Discharge, ft³/s
0.20	0.046	0.55	0.564	0.90	1.92
.21	.052	.56	.590	.91	1.97
.22	.058	.57	.617	.92	2.02
.23	.065	.58	.644	.93	2.08
.24	.072	.59	.672	.94	2.13
.25	.080	.60	.700	.95	2.19
.26	.088	.61	.730	.96	2.25
.27	.096	.62	.760	.97	2.31
.28	.106	.63	.790	.98	2.37
.29	.115	.64	.822	.99	2.43
.30	.125	.65	.854	1.00	2.49
.31	.136	.66	.887	1.01	2.55
.32	.147	.67	.921	1.02	2.61
.33	.159	.68	.955	1.03	2.68
.34	.171	.69	.991	1.04	2.74
.35	.184	.70	1.03	1.05	2.81
.36	.197	.71	1.06	1.06	2.87
.37	.211	.72	1.10	1.07	2.94
.38	.226	.73	1.14	1.08	3.01
.39	.240	.74	1.18	1.09	3.08
.40	.256	.75	1.22	1.10	3.15
.41	.272	.76	1.26	1.11	3.22
.42	.289	.77	1.30	1.12	3.30
.43	.306	.78	1.34	1.13	3.37
.44	.324	.79	1.39	1.14	3.44
.45	.343	.80	1.43	1.15	3.52
.46	.362	.81	1.48	1.16	3.59
.47	.382	.82	1.52	1.17	3.67
.48	.403	.83	1.57	1.18	3.75
.49	.424	.84	1.61	1.19	3.83
.50	.445	.85	1.66	1.20	3.91
.51	.468	.86	1.71	1.21	3.99
.52	.491	.87	1.76	1.22	4.07
.53	.515	.88	1.81	1.23	4.16
.54	.539	.89	1.86	1.24	4.24
				1.25	4.33

the water surface downstream from the flume is far enough above the elevation of the flume crest to reduce the discharge. For free flow, only the head, H_a, at the upstream gauge location is needed to determine the discharge from a standard table. The free-flow range includes some of the range that might ordinarily be considered submerged flow because Parshall flumes tolerate 50 to 80 percent submergence before the free-flow rate is measurably reduced. For submerged flows (when submergence is greater than 50 to 80 percent, depending upon flume size), both the upstream and downstream heads, H_a and H_b, are needed to determine the discharge (see fig. 3-8 for locations of the gauges).

A distinct advantage of the Parshall flume is its ability to function as a flowmeter over a wide operating range with minimum loss of head while requiring only one head measurement for each discharge. The head



SEEPAGE READINGS

Modified 8-20-85 for Sugar Loaf Dam
Observer(s) Fred
Reservoir Elev. 9868.68
Sheet 1 of 1
Date 7-16-85

MEASURING DEVICE NO.	LOCATION		READING** (GPM)	REMARKS•
	NORTH	EAST		
SM-1	253,771	918,766	5.40	
SM-2	254,511	918,218		Not read

Report precipitation for a week prior reading.
***Report even if reading is dry. Dry reading is assumed as a zero reading.*

Figure 3-6.—Example field data form for flow measurements.

loss is only about one-fourth of that needed to operate a weir having the same crest length. Another advantage is that the velocity of approach is automatically controlled if the correct flume size is chosen and the flume is used properly, that is, as an in-line structure.

The main disadvantages of Parshall flumes are (1) they cannot be used in close-coupled combination structures consisting of a turnout, control, and measuring device, (2) they usually cost more than weirs or submerged orifices, (3) they require a solid, watertight foundation, and (4) they require accurate workmanship for satisfactory construction and performance.

Parshall flume sizes are designated by the throat width, W. They are available in standard dimensions from the 1-inch size, for discharges as small as 0.01 ft^3/s, up to the 50-foot size, for discharges as large as 3,000 ft^3/s. Parshall flumes may be built of wood, concrete, galvanized sheet metal, or other materials.

b. ***Principles of Operation.***—(1) *Free-Flow Conditions.*—In free-flow conditions, the discharge depends solely on the width of the throat, W, and the depth of water, H_a, at the gauging point in the converging section of the flume.

(2) *Submerged Flow Conditions.*—In most installations, when the discharge is increased above a critical value, the resistance to flow in the downstream channel becomes sufficient to reduce the velocity, increase the flow depth, and cause a backwater effect at the Parshall flume. Although it might be expected that the discharge would decrease as soon as the backwater level, H_b, exceeds the elevation of the flume crest, this is not the case. Calibration tests show that the discharge is not reduced until the submergence ratio, H_b/H_a, expressed in percent, exceeds the following values:

50 percent for flumes 1, 2, and 3 inches wide,
60 percent for flumes 6 and 9 inches wide,
70 percent for flumes 1 to 8 feet wide, and
80 percent for flumes 8 to 50 feet wide.

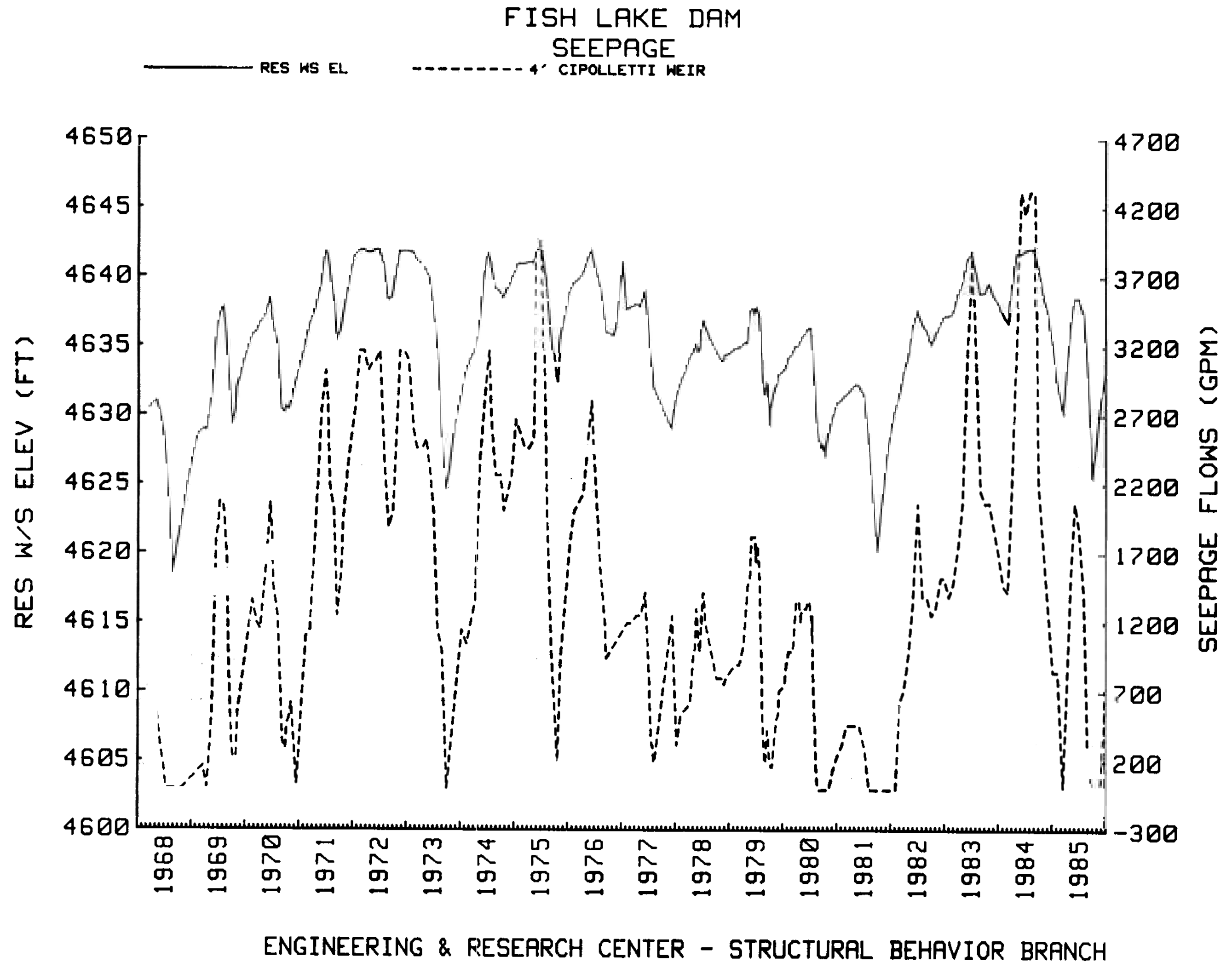


Figure 3-7.—Example plot of seepage and reservoir level from weir data.

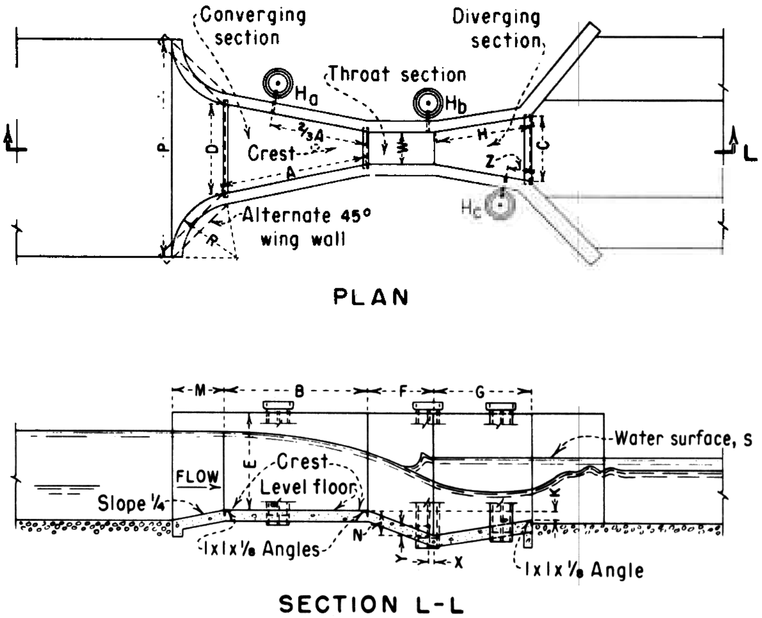
c. ***Dimensional Characteristics.***—Figure 3-9 lists the dimensional relationship of flumes ranging in width from 1 inch to 50 feet. Free-flow capacities are also shown. On figure 3-8, the length of the wall of the converging section, A, in feet is:

$$A = \frac{W}{2} + 4 \tag{6}$$

where W is the throat width in feet.

The measuring station for the upstream head, H_a, should be located in the converging wall a distance $\frac{2}{3}A$ upstream from the throat entrance. The measuring station for the downstream head, H_b, should be located in the same place for all sizes 6-inches through 8-feet: 2 inches upstream from the low point in the floor and 3 inches above it. When placing the flumes in canals and laterals, the crest invert section must be leveled carefully, both in the direction of flow and transverse to it. When the gauge zeros are established, they should be set so both the H_a and the H_b gauges read the depths above the crest—not the depths above the pressure opening.

The capacity of very small flumes ranges from about 0.01 ft³/s for H_a = 0.10 foot in the 1-inch flume, to 1.134 ft³/s for H_a = 1.0 foot in the 3-inch flume. The capacity of each size of flume overlaps that of the next



PLAN

SECTION L-L

Figure 3-8.—Parshall flume, plan and section. 103-D-870.

	W		A		⅔A		B		C		D		E		F		G		H		K		M		N		P		R		X		Y		Z[4]		FREE-FLOW CAPACITY	
																																					MINIMUM	MAXIMUM
	FT.	IN.	FT.	IN.	FT.	IN.	FT.	IN.	FT.	IN.	FT.	IN.	FT.	IN.	FT.	IN.	FT.	IN.	FT.	IN.	FT.	IN.	FT.	IN.	FT.	IN.	FT.	IN.	FT.	IN.	FT.	IN.	FT.	IN.	FT.	IN.	SEC.-FT.	SEC.-FT.
[2]	0	1[1]	1	2 9/32	0	9 17/32	1	2	0	3 21/32	0	6 19/32	0	6 to 9	0	3	0	8	0	8 1/8	0	3/4	–	–	0	1 1/8		–	–		0	5/16	0	1/2	0	1/8	0.01	0.19
		2[1]	1	4 5/16		10 7/8	1	4		5 5/16		8 13/32		6 to 10		4 1/2		10		10 1/8		7/8		–		1 11/16		–	–			5/8		1		1/4	.02	.47
		3[1]	1	6 3/8	1	1/4	1	6		7		10 3/16	1 to 1 1/2			6	1	0	1	5/32		1	–			2 1/4		–	–			1		1 1/2		1/2	.03	1.13
[3]	0	6	2	7/16	1	4 5/16	2	0	1	3 1/2	1	3 5/8	2	0		0	2	0	–		0	3	1	0	0	4 1/2	2	11 1/2	1	4	0	2	0	3	–		.05	3.9
		9	2	10 5/8	1	11 1/8	2	10	1	3	1	10 5/8	2	6		0	1	6	–			3	1	0		4 1/2	3	6 1/2	1	4		2		3	–		.09	8.9
	1	0	4	6	3	0	4	4 7/8	2	0	2	9 1/4	3	0	2	0	3	0	–			3	1	3		9	4	10 3/4	1	8		2		3	–		.11	16.1
	1	6	4	9	3	2	4	7 7/8	2	6	3	4 3/8	3	0	2	0	3	0	–			3	1	3		9	5	6	1	8		2		3	–		.15	24.6
	2	0	5	0	3	4	4	10 7/8	3	0	3	11 1/2	3	0	2	0	3	0	–			3	1	3		9	6	1	1	8		2		3	–		.42	33.1
	3	0	5	6	3	8	5	4 3/4	4	0	5	1 7/8	3	0	2	0	3	0	–			3	1	3		9	7	3 1/2	1	8		2		3	–		.61	50.4
	4	0	6	0	4	0	5	10 5/8	5	0	6	4 1/4	3	0	2	0	3	0	–			3	1	6		9	8	10 3/4	2	0		2		3	–		1.3	67.9
	5	0	6	6	4	4	6	4 1/2	6	0	7	6 5/8	3	0	2	0	3	0	–			3	1	6		9	10	1 1/4	2	0		2		3	–		1.6	85.6
	6	0	7	0	4	8	6	10 3/8	7	0	8	9	3	0	2	0	3	0	–			3	1	6		9	11	3 1/2	2	0		2		3	–		2.6	103.5
	7	0	7	6	5	0	7	4 1/4	8	0	9	11 3/8	3	0	2	0	3	0	–			3	1	6		9	12	6	2	0		2		3	–		3.0	121.4
	8	0	8	0	5	4	7	10 1/8	9	0	11	1 3/4	3	0	2	0	3	0	–			3	1	6		9	13	8 1/4	2	0		2		3	–		3.5	139.5
	10	0	–		6	0	14	0	12	0	15	7 1/4	4	0	3	0	6	0	–		0	6	–			1 1/2	–		–		0	9	1	0	–		6	200
	12	0	–		6	8	16	0	14	8	18	4 3/4	5	0	3	0	8	0	–			6	–			1 1/2	–		–			9	1	0	–		8	350
	15	0	–		7	8	25	0	18	4	25	0	6	0	4	0	10	0	–			9	–			6	–		–			9	1	0	–		8	600
	20	0	–		9	4	25	0	24	0	30	0	7	0	6	0	12	0	–			0	–		2	3	–		–			9	1	0	–		10	1000
	25	0	–		11	0	25	0	29	4	35	0	7	0	6	0	13	0	–			0	–		2	3	–		–			9	1	0	–		15	1200
	30	0	–		12	8	26	0	34	8	40	4 3/4	7	0	6	0	14	0	–			0	–		2	3	–		–			9	1	0	–		15	1500
	40	0	–		16	0	27	0	45	4	50	9 1/2	7	0	6	0	16	0	–			0	–		2	3	–		–			9	1	0	–		20	2000
	50	0	–		19	4	27	0	56	8	60	9 1/2	7	0	6	0	20	0	–		1	0	–		2	3	–		–			9	1	0	–		25	3000

[1] Tolerance on throat width (w) ± 1/64 inch; tolerance on other dimensions ± 1/32 inch. Sidewalls of throat must be parallel and vertical.

[2] From Colorado State University Technical Bulletin No. 61.

[3] From U.S. Department of Agriculture Soil Conservation Circular No. 843.

[4] From Colorado State University Bulletin No. 426-A

Figure 3-9.—Parshall flume dimensions and free-flow discharge capacities. Symbols relate to dimensions on figure 3-8. 103-D-861 size by about one-half the discharge range. To visualize the very small flows, it is helpful to recall that 0.01 ft^3/s is approximately equal to 4.5 gallons per minute.

d. ***Installation Procedures.***—When installing very small flumes, the crest should be used as an index. Careful leveling is necessary in both longitudinal and transverse directions if standard discharge tables are to be used. The flume should be set on a solid foundation to prevent settlement or heaving. Collars should be attached to either or both the upstream and downstream flanges of the flume, and should extend well into the channel banks and below the invert to prevent flow from bypassing the structure and eroding the foundation. Careful zeroing and reading of the staff gauges is necessary for accurate results. An error of 0.01 foot (about 1/8 inch) in setting the flume or in setting the gauge zero, combined with a 0.01-foot error in reading the staff gauge, could result in an error of 8 percent in the discharge determination in a mid-range flow for the 2-inch flume. For the 1-inch flume, similar setting and reading errors could result in a discharge determination error of 12 percent. The importance of extra precautions in setting and reading the gauges in these small flumes is evident.

e. ***Discharge Determinations.***—The discharge in free-flow conditions should be determined by reading the H_a value and referring to a table giving discharge values for the particular size of flume. For example, table 3-4 covers the discharge values for free-flow conditions through a 6-inch flume. Tables 14-27 (pp. 273-287) of the *Water Measurement Manual* contain discharges for different flume sizes.

For submerged flow where the submergence is sufficiently great to affect the rate of flow, figures such as 3-10 should be used to determine the discharge after both the H_a and H_b values are read. The submergence ratio is computed by dividing the H_b value by the H_a value.

Turbulence and the relatively deep and narrow throat sections have made reading the H_b gauge difficult in the 1-, 2-, and 3-inch flumes. Consequently, an H_c gauge, located near the downstream end of the diverging portion of the flume (see fig. 3-8) was added. This gauge may be read instead of the H_b gauge. The H_c readings should be converted to H_b readings by using a graph like that on figure 3-11. These H_b values should then be used in the discharge determinations.

f. ***Data Processing and Review***—The field data are entered on a field data form as shown on figure 3-6 and submitted to the Structural Behavior Branch. Upon arrival, the data are processed and reviewed as indicated in section 25. Plots similar to the example on figure 3-12 are generated for study of seepage quantities with relation to reservoir level and past seepage history.

41. Trapezoidal Flumes.—a. ***Usage.***—Trapezoidal flumes can be used in any straight section of channel. They have been found particularly useful for measuring small flows.

b. ***Description of Equipment.***—Several types of trapezoidal flumes are available commercially. They are supplied as a precast unit of molded hard plastic. Typical sizes are 2-inch and 12-inch throat widths with capacities of 0.01 to 7.1 ft^3/s, respectively. Either 45 or 60° sloping sides are available. The precast units range from about 2.5 to 5.5 feet in length and 7 to 16 inches in height. Figure 3-13 illustrates a typical trapezoidal flume.

A head gauge labeled h_1 is provided at the inlet end of the flume, and another labeled h_4 is provided at the flume outlet.

c. ***Installation.***—Trapezoidal flumes are installed in ditches or earthern channels after excavation to the proper dimensions for the precast unit. The unit is then placed with the flume floor located at or slightly above the existing channel floor. It is very important that the unit fit well with the channel. Backfilling must be done carefully with well-compacted low permeability soils or by using sand-cement grout. No flow around or below the precast unit is allowed.

If possible, a flume should be installed so that the entire flume flow is level. For a channel with a sloping floor, the head gauges must be corrected so that each gauge zero is at the exact elevation as the flume throat floor.

Whenever possible, flumes should be operated under free-flow conditions. However, it is sometimes necessary to raise the flume somewhat to achieve this free-flow condition. A flume is considered to be operating in a free-flow condition when the level at h_4 is less than about 70 percent of the level at h_1. A submerged (not free-flow) condition requires that the flow be corrected using the correction tables supplied with the unit.

d. ***Monitoring Procedure.***—Under normal operation, only the inlet head gauge, h_1, is read. This value is referenced to a table (table 3-5 is typical) for the proper size and type of flume, and the flow (discharge) is determined. The data are entered on a field data form as shown on figure 3-14.

Table 3-4.—Free-flow discharge through 6-inch Parshall flume. Computed from the formula, $Q = 2.06\ H_a^{1.58}$.

Upper head, H_a, ft	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.10	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12	0.14	0.15
.20	.16	.18	.19	.20	.22	.23	.25	.26	.28	.29
.30	.31	.32	.34	.36	.38	.39	.41	.43	.45	.47
.40	.48	.50	.52	.54	.56	.58	.61	.63	.65	.67
.50	.69	.71	.73	.76	.78	.80	.82	.85	.87	.89
.60	.92	.94	.97	.99	1.02	1.04	1.07	1.10	1.12	1.15
.70	1.17	1.20	1.23	1.26	1.28	1.31	1.34	1.36	1.39	1.42
.80	1.45	1.48	1.50	1.53	1.56	1.59	1.62	1.65	1.68	1.71
.90	1.74	1.77	1.81	1.84	1.87	1.90	1.93	1.97	2.00	2.03
1.00	2.06	2.09	2.12	2.16	2.19	2.22	2.26	2.29	2.32	2.36
1.10	2.40	2.43	2.46	2.50	2.53	2.57	2.60	2.64	2.68	2.71
1.20	2.75	2.78	2.82	2.86	2.89	2.93	2.97	3.01	3.04	3.08

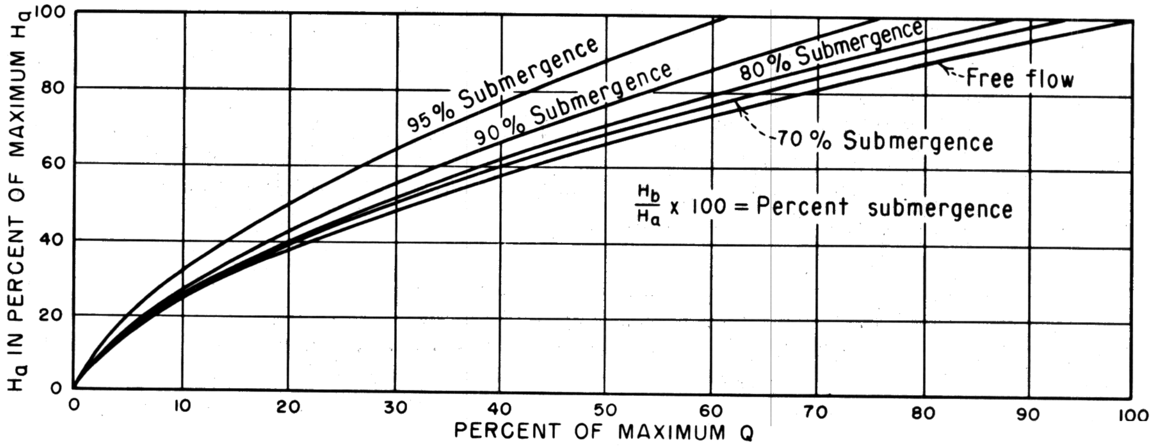


Figure 3-10.—Typical discharge curves for Parshall flumes with free-flow and with submerged conditions. 103-D-872.

e. ***Data Processing and Review.***—The field data form is transmitted to the Structural Behavior Branch for processing and review as described in section 25. Data plots are prepared for review as shown on figure 3-15.

42. Velocity Meters.—a. ***Usage.***—Several different types of velocity meters are available commercially. Their methods of operation vary. Some use the Pilot tube principal; others range from propeller-type devices to accoustic flowmeters to electromagnetic current indicators. Most of these devices can be used to measure the flow in pipes or in open channels. A relatively new device used by the USBR is the portable velocity meter (fig. 3-16), which operates on the principal of electromagnetic velocity determination. This device can be used for measuring water velocity in pipes or in open channels, which is then converted to quantity of flow.

b. ***Description of Equipment.***—The portable velocity meter probe operates on the elementary electromagnetic principle that a conductor moving through a magnetic field will have a voltage induced. In the velocity meter shown on figure 3-16, a signal is generated and sent to an electromagnet within the probe creating a magnetic field. The conductor is the water into which the probe is immersed.

As the water flows through the magnetic field, a voltage is generated in the water near the electrodes, which sense the voltage. This voltage is then transmitted through the cable to the surface unit, which amplifies and

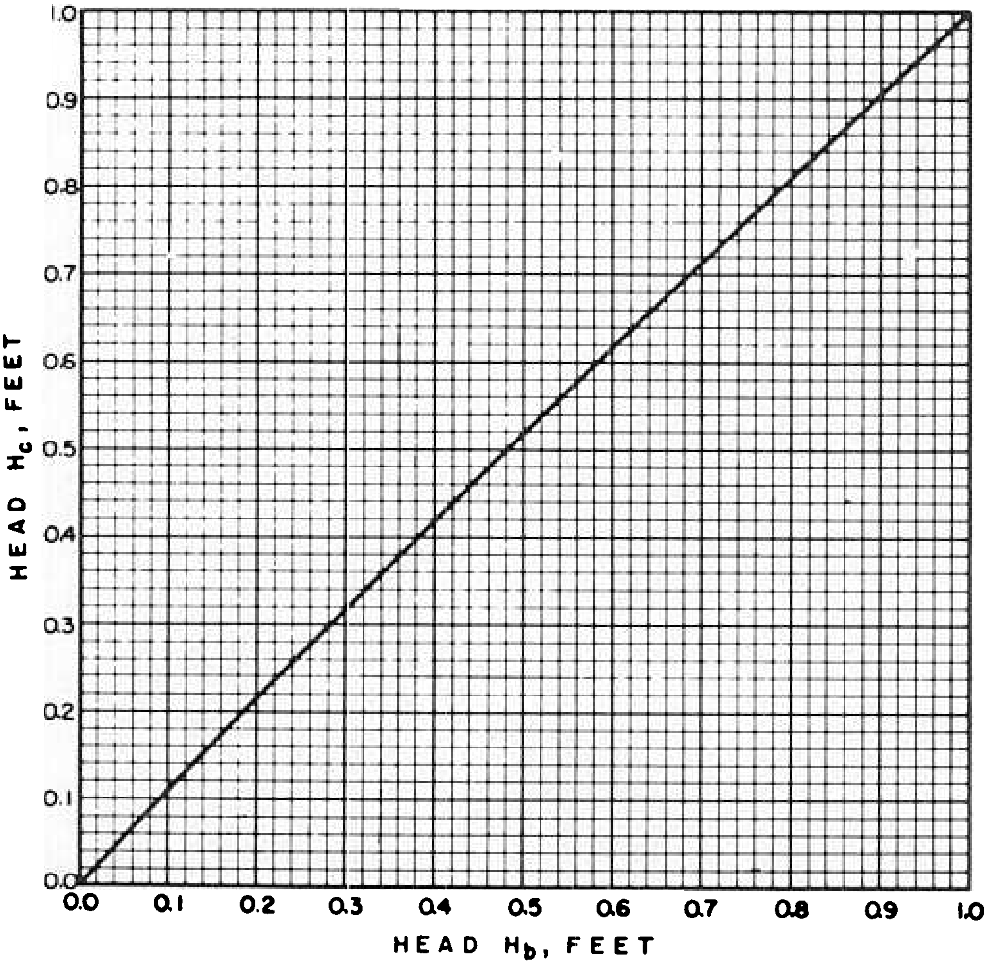


Figure 3-11.—Relationship of H_c and H_b gauges for 1-, 2-, and 3-inch Parshall flumes for submergences greater than 50 percent. 103-D-879. (Courtesy Colorado State University.)

conditions the signal and displays the results as a velocity measurement. The polarity and magnitude of this signal is directly proportional to the direction and velocity of the water.

The device consists of a probe, extension rods, and a surface readout unit, all of which are connected by cable. The unit is battery powered, light-weight, and portable. Calibration tests by USBR laboratories indicate an accuracy within 5 percent at low flows (0.1 ft^3/s) and 1 percent at higher flows (2.0 ft^3/s).

c. ***Installation.***—No installation is required for the portable velocity meter. The device is merely lowered into the flowing water and readings are taken.

d. ***Monitoring Procedure.***—The velocity meter is lowered into the flowing water with the switches set at NORMAL and ON. The water velocity in feet per second is read directly from the meter. For example, for measurements in a 12-inch-diameter pipe flowing 6 inches deep at a velocity of 2.0 ft/s, the depth of flow (to the nearest ⅛-inch) in the pipe can be located along the left side of table 3-6 and velocity can be located along the top of the table. For this example, a value of 0.509 Mgal/d(million gallons per day) is determined for the flow. Velocity values that are not whole numbers are entered as whole numbers and as fractions of whole numbers, then added together. For example, using the previous data and a measured velocity of 2.5 ft/s, the 0.509 Mgal/d flow is added to a value of 0.127 Mgal/d (which is $^1/_{10}$ flow in the 5 ft/s column, for a total flow of 0.636 Mgal/d.

Open channel flow may be determined by multiplying the velocity measured by the cross-sectional area of the channel to the depth of flow.

e. ***Data Processing and Review.***—The data are recorded on a field data form and submitted to the Structural Behavior Branch for handling and processing as described in section 25.

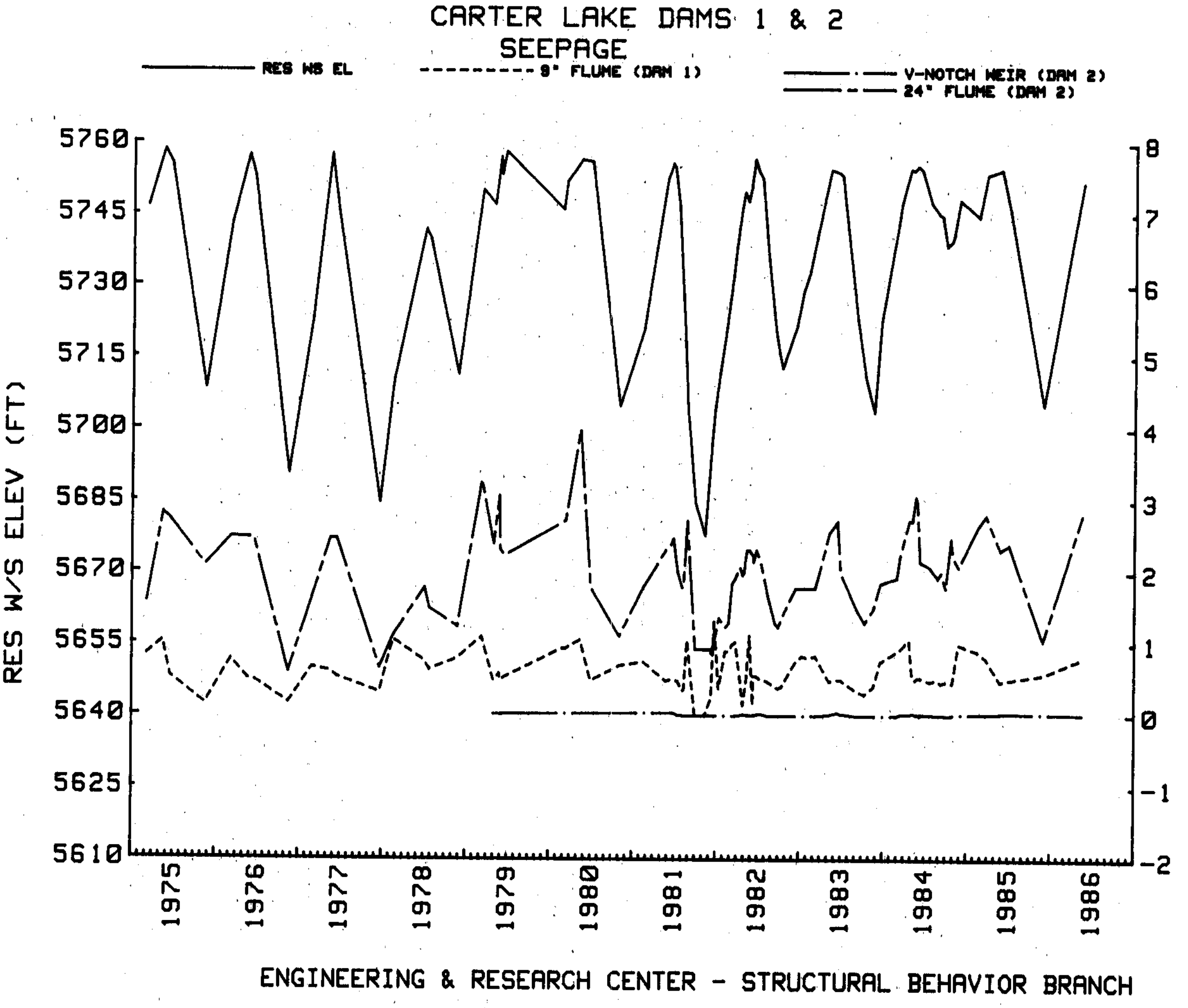


Figure 3-12.—Example plot of seepage and reservoir level from Parshall flume data.

43. Calibrated Container Devices.—The simplest method of monitoring quantity of flow from drains consists of merely catching a known quantity of water in a calibrated container and measuring the time required to do so. Such a method is normally, however, reserved for relatively low flow conditions.

This method requires that the drain water be either flowing through a pipe with an exposed end or that the channel the water is flowing in is constructed with a vertical drop with an overhang. Such facilities are necessary to be able to place the container in a position to catch the water.

Calibrated containers may be any size, but the sizes commonly used range from 1 pint to 5 gallons for convenience of handling. In operation, the container is held in a position to catch the total flow, and the time in minutes or fractions of minutes required to fill the container is noted. For example, if a 1.0-gallon container is filled in 1 minute, then the flow rate is 1 gallon per minute. Similarly, a 0.5 gallon container filled in 40 seconds indicates a flow rate of 0.75 gallons per minute.

44. Geophysical Seepage Measuring Methods.—**a.** ***Thermotic Surveys.***—(1) *General.*—It has been shown analytically and demonstrated in the field that flowing ground water (of even minor magnitude) influences near-surface soil temperatures to a measurable extent. References [12, 13, 14, 15, and 56] pertain to research and practice in this area.

Thermotic techniques are particularly useful in identifying zones or paths of high permeability and groundwater flow concentrations within fractured rock and surficial deposits. Although these techniques do not replace borings or conventional instrumentation, they can make other monitoring activities more accurate

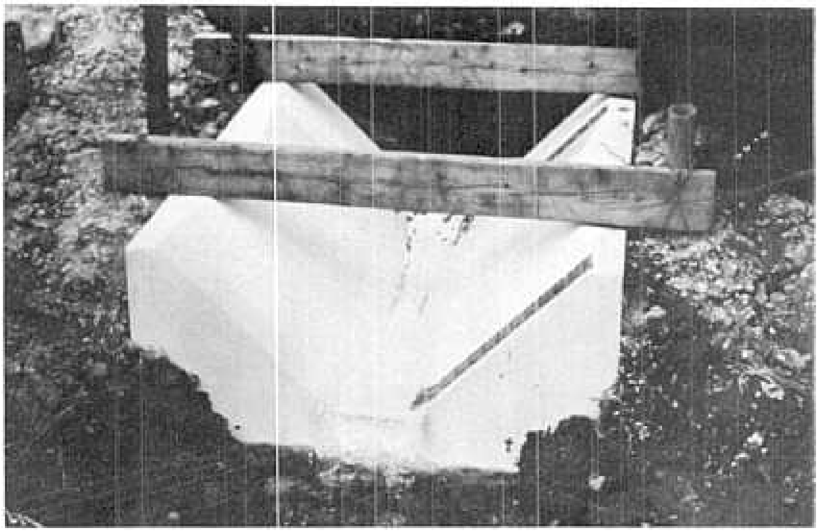


Figure 3-13.—Typical trapezoidal flume. P801-D-81015.

and economical by directing the location of more quantitative investigation methods such as drill holes, pump tests, etc.

The beneficial features of thermotic techniques include:

- Installation, maintenance, and data retrieval is inexpensive.
- No expensive test holes or pumping tests are required.
- The field equipment is easily portable.
- A grid of thermotic probes can be designed for site-specific evaluations.
- The grids can be easily altered as necessary.
- The system is readily automated.
- Thermotic probes are rugged, durable, and easily replaced.
- There is minimal environmental impact.
- Thermotic investigations supplement other more conventional techniques to provide a more complete evaluation of geologic site conditions.
- The preliminary evaluation is especially useful in establishing reference data representative of unaltered natural conditions. These data may be compared with later measurements during the first filling and afterward.

(2) *Usage.*—Variability in hydraulic conductivity is critical to controlling seepage at embankment damsites. Fractured rock is notoriously heterogeneous and anisotropic with respect to the orientation and frequency of bedding planes and fractures. Furthermore, depending on the fracture aperture and wall roughness, the velocity of seepage in fractured rock may differ from that in the surrounding medium by several orders of magnitude. This is especially true in massive, dense rock where seepage is along interconnected fractures, joints, and crevices. Because seepage in such media occurs along discrete, channelized flow paths, there is a very low probability that arbitrarily located piezometers or observation wells would be correctly positioned to detect anomalous flow conditions.

In the mathematical treatment of temperature variations caused by the normal fluctuations in heat at the surface of the earth over a one year period, it is customary to assume that temperature changes generate a heat wave that can be approximated by a sine curve. The temperatures resulting from such a wave can be readily calculated for any point beneath the surface. The differences between the calculated and the observed temperatures are due to heat transfer by fluids: the greater that difference, the larger the increment of heat transfer due to seepage flow.

(3) *Example Installation.*—A thermotic monitoring system was installed at Fontenelle Dam[1] in January, 1983, because conventional monitoring techniques were thought to be inadequate in identifying and

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[1] Fontenelle Dam is a zoned earthfill structure, 139.1 feet high and 5,421.0 feet long, located on the Green River in Lincoln County, Wyoming.

Table 3-5.—Typical table for trapezoidal flume discharge determinations.

	2-inch 45° WSC Trapezoidal flume Free-flow discharge in cubic feet per second									
Head*, ft	0.0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.1	0.023	0.028	0.033	0.038	0.044	0.051	0.058	0.065	0.073	0.081
.2	.090	.100	.110	.121	.132	.144	.156	.169	.183	.197
.3	.212	.228	.244	.261	.278	.297	.316	.336	.356	.377
.4	.399	.422	.445	.470	.495	.521	.547	.575	.603	.632
.5	.662	.693	.725	.757	.791	.825	.860	.896	.933	.971
.6	1.01	1.05	1.09	1.13	1.17	1.22	1.26	1.31	1.36	1.40
.7	1.45	1.50	1.55	1.60	1.66	1.71	1.77	1.82	1.88	1.94
.8	2.00	2.06	2.12	2.18	2.24	2.31	2.38	2.44	2.51	2.58
.9	2.65	2.72	280	2.87	2.95	3.02	3.10	3.18	3.26	3.34
1.0	3.42	3.51	3.59	3.68	3.77	3.86	3.95	4.04	4.13	4.23

Head measured vertically.

determining changes in the discrete, channelized seepage apparently existing within the foundation. Geothermal Surveys, Inc. of Pasedena, California, served as a consultant especially in the initial phases of this project.

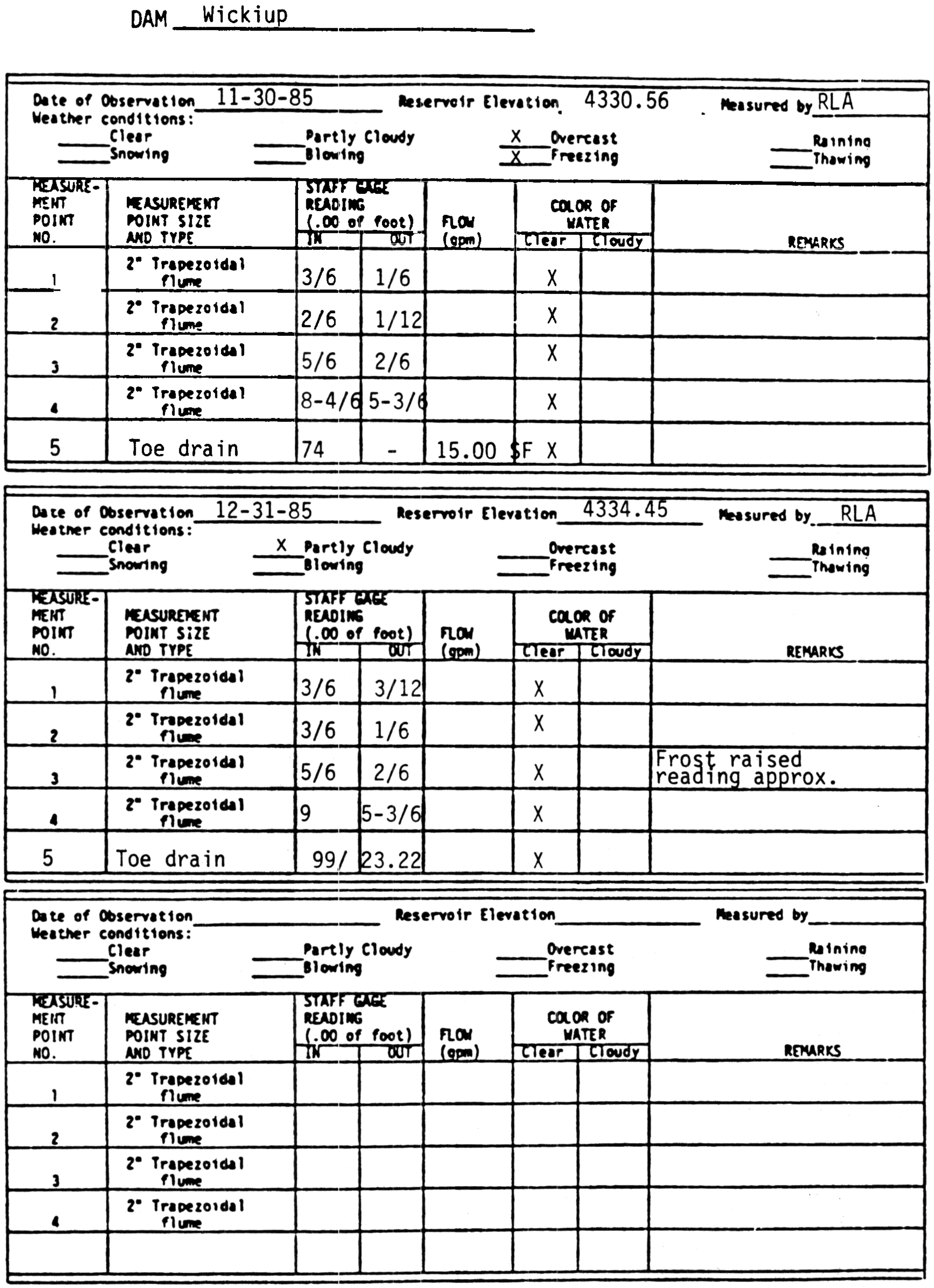
For the initial survey, the USBR installed 40 thermistors in ⅜-inch-diameter plastic pipes in 10-foot-deep holes. These holes were drilled in a line along the downstream toe of the dam starting at about station 43+00 and continuing east along the dam axis to the left abutment. Areas downstream of the grout curtain and the left abutment were also included, and observation wells within the study area were temperature logged. The system was later expanded to include 38 more thermistors along the entire downstream toe of the dam. Figures 3-17 and 3-18 show the locations of the thermistors. All probes were permanently installed and provided with quick connects at the surface for easy and frequent monitoring. Diurnal effects were avoided by installing thermistors with ±0.01 °C accuracy at 10-foot depths. The initial readings and interpretations were performed by Geothermal Surveys, Inc. Later readings and interpretations were performed by USBR personnel.

The temperatures recorded within seepage zones result from two primary forcing functions: the ambient air temperature and the mass transfer of heat (from water moving through the soil), which propagates upward to the thermistors by conduction. Frequent profiles of Fontenelle Reservoir have shown that little or no thermal stratification occurs: often there is as little as 1 °C difference between the temperatures of the bottom and the top 3 feet of the reservoir. Water temperatures closely follow the ambient cycle as a result of convective mixing, wind action, and the relatively high heat conductivity of the water.

The ambient air and reservoir water temperatures are therefore nearly in phase and experience much greater peak-to-peak amplitude than the soil cycle. This results in corresponding temperature changes in the subsurface soil and rock through which the seepage flows. The seepage water is then expected to raise soil temperatures in the overlying unsaturated zone in the summer and early fall and to lower them in the winter and early spring. Because the range of temperature fluctuation is much greater in the reservoir than in the ground, the variation of temperatures with time in the seepage zones is much higher than in the unaffected ground. Therefore, the extent to which soil temperatures relate to ambient and reservoir temperatures and the variance of temperatures with time are functions of the amount and rate of seepage flowing through the dam foundation.

The results of the thermotic survey conducted at Fontenelle Dam indicate that channelized flow is occurring at relatively high velocities at station 60+00 and is continuing in a downstream direction. The range of temperature fluctuation in this area is much greater than the range of temperature fluctuation in the ground reference station on the left abutment and other areas along the toe of the dam. This area is in the vicinity of maximum embankment settlement. Wet areas and flowing water have also been noted along the downstream toe of the embankment in this area. In observation well OB-26, significant foundation seepage was observed spraying into the hole through a large vertical fracture at approximately the same elevation as the embankment cutoff trench-foundation contact.

In addition to this narrow flow path, the thermotic surveys indicate a somewhat broader seepage zone between approximately stations 52+00 and 61+00. Another broad seepage zone is indicated between stations



DAM Wickiup

Date of Observation 11-30-85 Reservoir Elevation 4330.56 Measured by RLA
Weather conditions:
___ Clear ___ Partly Cloudy X Overcast ___ Raining
___ Snowing ___ Blowing X Freezing ___ Thawing

MEASURE-MENT POINT NO.	MEASUREMENT POINT SIZE AND TYPE	STAFF GAGE READING (.00 of foot)		FLOW (gpm)	COLOR OF WATER		REMARKS
		IN	OUT		Clear	Cloudy	
1	2" Trapezoidal flume	3/6	1/6		X		
2	2" Trapezoidal flume	2/6	1/12		X		
3	2" Trapezoidal flume	5/6	2/6		X		
4	2" Trapezoidal flume	8-4/6	5-3/6		X		
5	Toe drain	74	-	15.00 SF	X		

Date of Observation 12-31-85 Reservoir Elevation 4334.45 Measured by RLA
Weather conditions:
___ Clear X Partly Cloudy ___ Overcast ___ Raining
___ Snowing ___ Blowing ___ Freezing ___ Thawing

MEASURE-MENT POINT NO.	MEASUREMENT POINT SIZE AND TYPE	STAFF GAGE READING (.00 of foot)		FLOW (gpm)	COLOR OF WATER		REMARKS
		IN	OUT		Clear	Cloudy	
1	2" Trapezoidal flume	3/6	3/12		X		
2	2" Trapezoidal flume	3/6	1/6		X		
3	2" Trapezoidal flume	5/6	2/6		X		Frost raised reading approx.
4	2" Trapezoidal flume	9	5-3/6		X		
5	Toe drain	99/	23.22		X		

Date of Observation ___ Reservoir Elevation ___ Measured by ___
Weather conditions:
___ Clear ___ Partly Cloudy ___ Overcast ___ Raining
___ Snowing ___ Blowing ___ Freezing ___ Thawing

MEASURE-MENT POINT NO.	MEASUREMENT POINT SIZE AND TYPE	STAFF GAGE READING (.00 of foot)		FLOW (gpm)	COLOR OF WATER		REMARKS
		IN	OUT		Clear	Cloudy	
1	2" Trapezoidal flume						
2	2" Trapezoidal flume						
3	2" Trapezoidal flume						
4	2" Trapezoidal flume						

Figure 3-14.—Example form for 2-inch, 45° WSC trapezoidal flume field data.

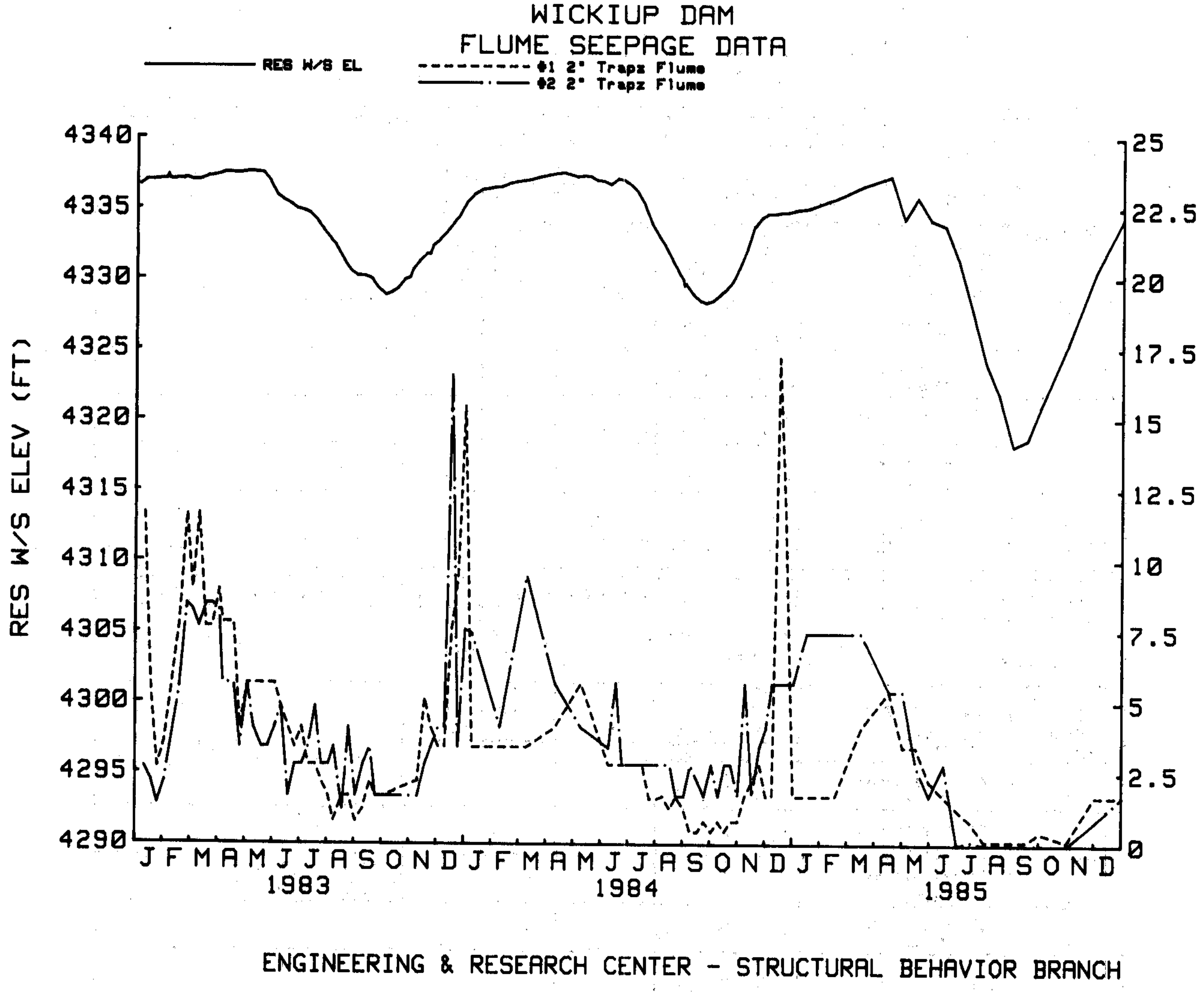


Figure 3-15.—Example plot of seepage and reservoir level from trapezoidal flume data.

42+00 and 44+00. This was confirmed by piezometers, which show an elevated ground-water mound in this region. Pumping-out tests also indicate very high values of hydraulic conductivity in this area.

The thermotic anomaly indicated by probe TH-53 at station 30+90.5 may be influenced by discharge waters flowing through a nearby conduit. The rate and magnitude of temperature change between probes TH-41 and TH-43 (stations 19+06 and 20+06) correspond closely to the change at the ground reference stations beneath which seepage is assumed to be zero. The anomalous variance in temperature between probes TH-45 and TH-49 (stations 22+03 to 25+81), however, indicates significant seepage beneath the embankment in this area.

The results from the pumping-out and pumping-in tests conducted at various locations along the downstream toe of the dam and from the geologic investigation confirmed without exception the existence of the anomalous seepage zones identified by thermotic monitoring methods.

(4) *Installation.*—A thermistor probe should be installed by the following method (fig. 3-19):

(a) Drill 4-inch-diameter hole, 10 feet deep. This may be done by any drilling method, using no drilling fluids except water.

(b) Install ½-inch schedule 80 PVC pipe, 12.5 feet long with a rubber stopper on the end, in the drill hole. Backfill the hole with the existing soil material (drill cuttings), tamping as the materials are placed. Install protective pipe with locking cap at the ground surface (see fig. 3-19).

(c) Install the thermistor in the PVC pipe with the three prong connector remaining outside the pipe. The thermistor can be easily removed and replaced if damaged or is malfunctioning.

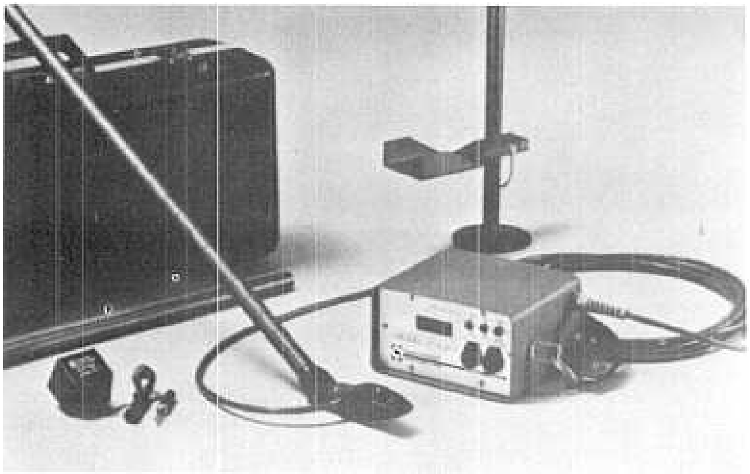


Figure 3-16.—Portable velocity meter. P801-D-81016.

(5) *Monitoring Procedure.*—Monitoring the thermistor data is relatively simple and requires little effort. The temperature may be read in either °F or °C from the temperature readout box, which should be attached to the three-prong connector on the thermistor probe. As it is taken, each reading must be compared with the previous reading.

(6) *Maintenance.*—Periodic problems, resulting in false readings, have occurred at the connections between the wires from the thermistor and the three-pronged plug. This problem can be corrected by ensuring that these connections are well made. The maintenance required at a thermistor installation consists simply of recharging the battery in the readout unit.

(7) *Data Processing.*—The data are recorded on a field data form as shown on figure 3-20, and submitted to the Structural Behavior Branch, where it is handled and processed as described in section 25.

b. ***Self-Potential Surveys.***—It has been demonstrated that water which is low in TDS (total dissolved solids) generates an electrical current when forced to flow under laminar flow conditions through porous earth materials. This phenomenon has been used to investigate seepage loss from various reservoirs around the world. Normally, a geophysical-type investigation, using a portable electrode device, is performed within the reservoir area to detect the origins of seepage paths. Recently, however, the USBR and others have used methods whereby fixed position electrodes have been used to detect self-potential or streaming potential downstream of reservoirs. These more permanent installations are expected to illuminate trends and forewarn the data reviewers of worsening situations.

Monitoring streaming potentials downstream of a dam is thought to be of greatest value at locations of relatively simple geologic configuration and where the possibility of discrete seepage paths makes piezometer data inadequate. When using electrodes instead of piezometers, a larger area can be monitored in more detail for less expense. Practical detection is generally thought to extend to a depth of 1,000 feet.

The theory for streaming potential states that an electrical potential exists between points along a capillary tube and a direct relationship exists between that voltage and the driving pressure. The generation of a current is thought to be the result of the displacement of the positively charged mobile portion of the double electric layer that is formed by unbalanced charges on the surface of mineral particles. The potential difference across the double layer is known as the zeta, or electrokinetic, potential. The zeta potential is a function of the conductivity and dielectric constant of the solution (i.e., ground water) and the electrical nature of the solids. For a given set of conditions describing the pertinent characteristics of ground water and earth materials, the zeta potential is constant. The streaming potential, which relates one region of flow to another, varies directly in magnitude with the differences in flow velocity.

Zeta potential varies indirectly with the conductivity of the solution. If the resistivity of the fluid is low (i.e., water high in TDS), detectable voltages are not generated. Without the zeta potential, there can be no streaming potential.

Table 3-6.—Flows through a 12-inch round pipe, million gallons per day.

Depth inch	Velocity, feet per second									
		2	3	4	5	6	7	8	9	10
0.125	0.001	0.002	0.003	0.004	0.005	0.005	0.006	0.007	0.008	0.009
.250	.003	.005	.008	.010	.013	.015	.018	.021	.023	.026
.375	.005	.009	.014	.019	.024	.028	.033	.038	.043	.047
.500	.007	.015	.022	.029	.036	.044	.051	.058	.065	.073
.625	.010	.020	.030	.040	.051	.061	.071	.081	.091	.101
.750	.013	.026	.040	.053	.066	.079	.093	.106	.119	.132
.875	.017	.033	.050	.067	.083	.100	.116	.133	.150	.166
1.000	.020	.041	.061	.081	.101	.122	.142	.162	.182	.203
1.125	.024	.048	.072	.096	.120	.145	.169	.193	.217	.241
1.250	.028	.056	.084	.112	.141	.169	.197	.225	.253	.281
1.375	.032	.065	.097	.129	.162	.194	.226	.259	.291	.323
1.500	.037	.073	.110	.147	.184	.220	.257	.294	.330	.367
1.625	.041	.082	.124	.165	.206	.247	.289	.330	.371	.412
1.750	.048	.092	.138	.184	.230	.276	.322	.367	.413	.459
1.875	.051	.102	.152	.203	.254	.305	.355	.406	.457	.508
2.000	.056	.111	.167	.223	.279	.334	.390	.446	.502	.557
2.125	.061	.122	.182	.243	.304	.365	.426	.487	.547	.608
2.250	.066	.132	.198	.264	.330	.396	.462	.528	.594	.660
2.375	.071	.143	.214	.285	.357	.428	.499	.571	.642	.714
2.500	.077	.154	.230	.307	.384	.461	.537	.614	.691	.768
2.625	.082	.165	.247	.329	.412	.494	.576	.658	.741	.823
2.750	.088	.176	.264	.352	.440	.528	.616	.703	.791	.879
2.875	.094	.187	.281	.375	.468	.562	.656	.749	.843	.937
3.000	.099	.199	.298	.398	.497	.597	.696	.796	.895	.995
3.125	.105	.211	.316	.421	.527	.632	.737	.843	.948	1.053
3.250	.111	.223	.334	.445	.557	.668	.779	.890	1.002	1.113
3.375	.117	.235	.352	.469	.587	.704	.821	.939	1.056	1.173
3.500	.123	.247	.370	.494	.617	.741	.864	.988	1.111	1.234
3.625	.130	.259	.389	.518	.648	.778	.907	1.037	1.166	1.296
3.750	.136	.272	.408	.543	.679	.815	.951	1.087	1.223	1.358
3.875	.142	.284	.426	.569	.711	.853	.995	1.137	1.279	1.421
4.000	.148	.297	.445	.594	.742	.891	1.039	1.188	1.336	1.485
4.125	.155	.310	.465	.619	.774	.929	1.084	1.239	1.394	1.549
4.250	.161	.323	.484	.645	.807	.968	1.129	1.290	1.452	1.613
4.375	.168	.336	.503	.671	.839	1.007	1.175	1.342	1.510	1.678
4.500	.174	.349	.523	.697	.872	1.046	1.220	1.395	1.569	1.743
4.625	.181	.362	.543	.724	.904	1.085	1.266	1.447	1.628	1.809
4.750	.187	.375	.562	.750	.937	1.125	1.312	1.500	1.687	1.875
4.875	.194	.388	.582	.777	.971	1.165	1.359	1.553	1.747	1.941
5.000	.201	.402	.602	.803	1.004	1.205	1.406	1.606	1.807	2.008
5.125	.207	.415	.622	.830	1.037	1.245	1.452	1.660	1.867	2.075
5.250	.214	.428	.643	.857	1.071	1.285	1.499	1.714	1.928	2.142
5.375	.221	.442	.663	.884	1.105	1.326	1.547	1.768	1.988	2.209
5.500	.228	.455	.683	.911	1.138	1.366	1.594	1.822	2.049	2.277
5.625	.234	.469	.703	.938	1.172	1.407	1.641	1.876	2.110	2.345
5.750	.241	.482	.724	.965	1.206	1.447	1.689	1.930	2.171	2.412
5.875	.248	.496	.744	.992	1.240	1.488	1.736	1.984	2.232	2.480
6.000	.254	.509	.763	1.018	1.272	1.527	1.781	2.036	2.290	2.545

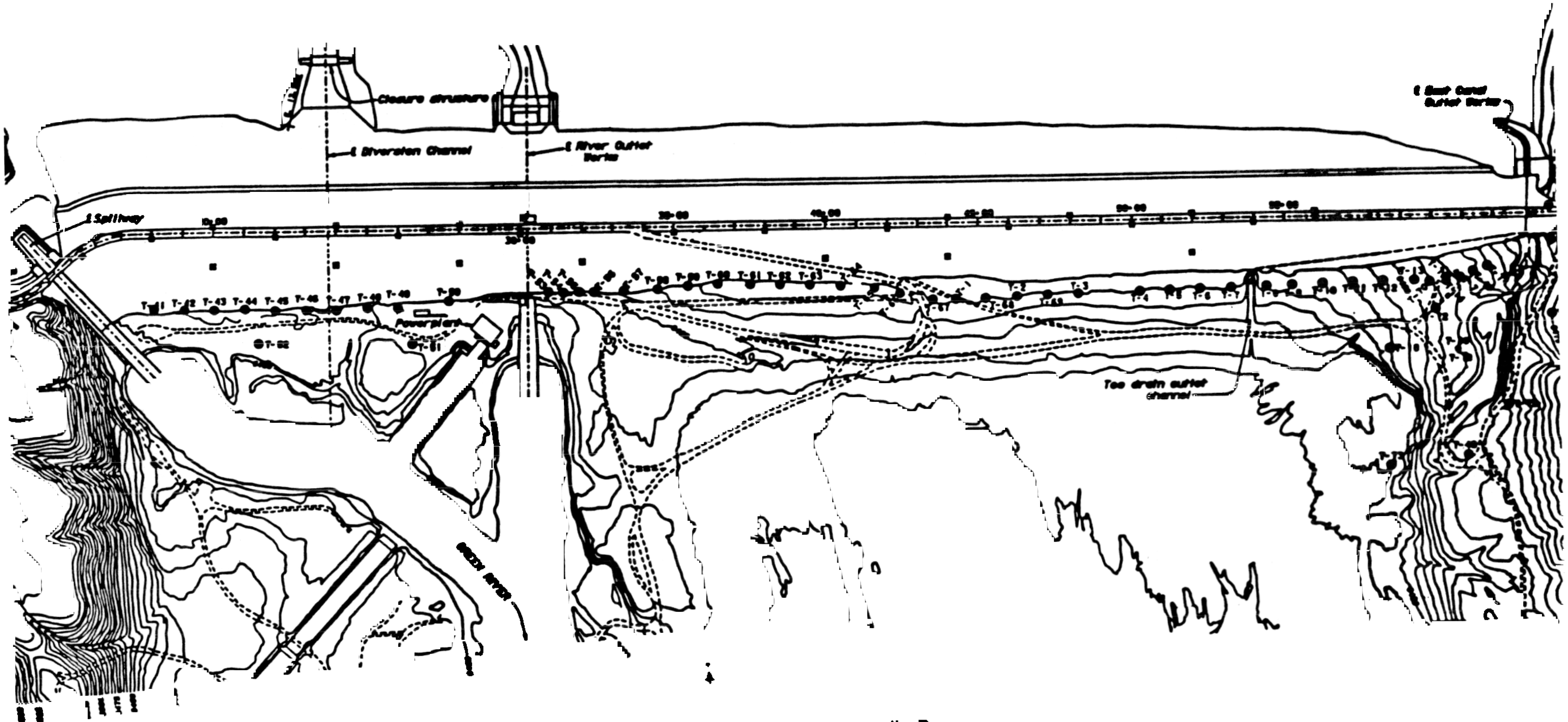


Figure 3-17.—Locations of thermistors at Fontanelle Dam.

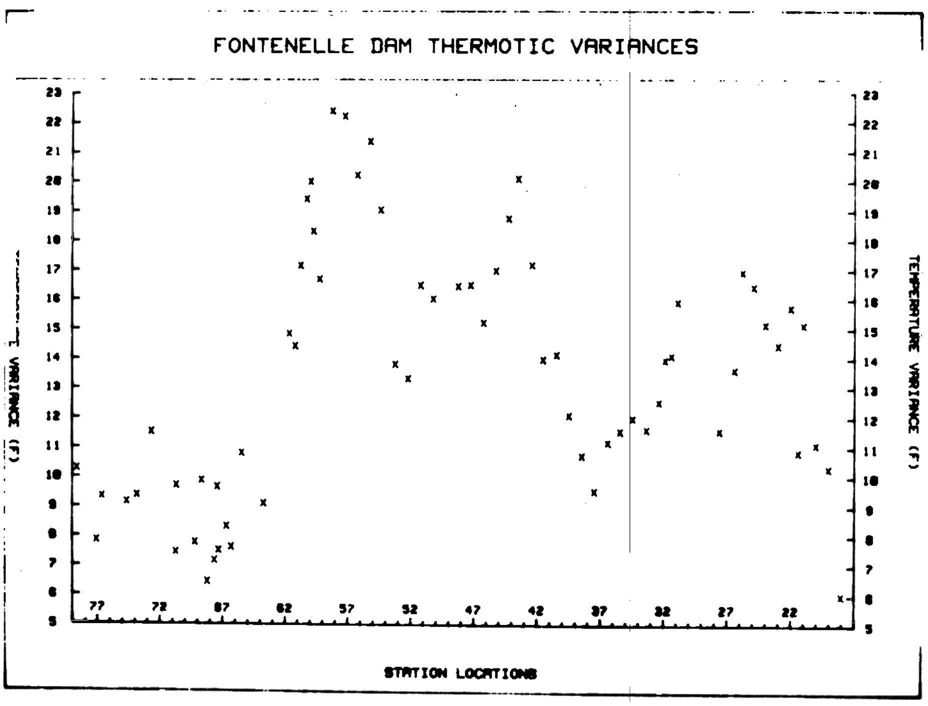


Figure 3-18.—Results of the thermotic survey.

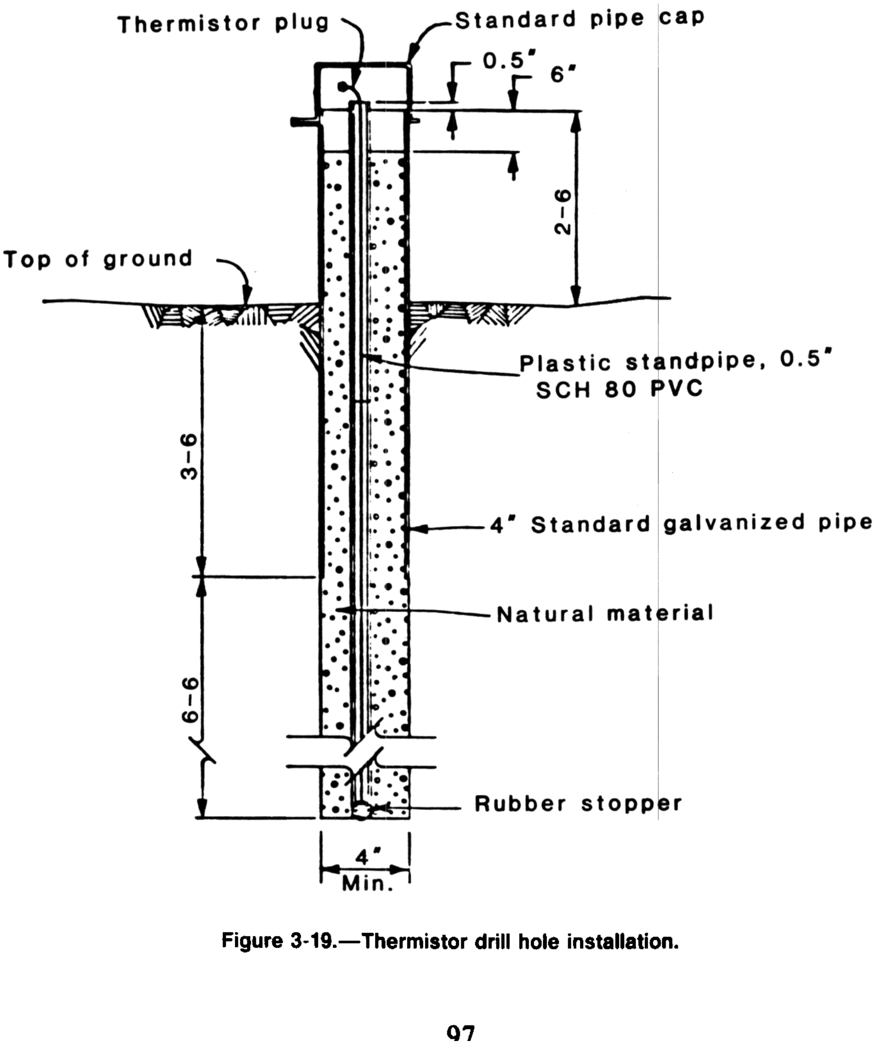


Figure 3-19.—Thermistor drill hole installation.

Dam Name Fontenelle

Date 09/17/85

Reservoir Elevation 6444.10

Temperature

Maximum Air Temperature

Minimum Air Temperature

Observer Barry Lawson

THERMISTOR NUMBER	READING	THERMISTOR NUMBER	READING
TH-1	58.650	TH-12	56.490
TH-2	56.580	TH-13	55.300
TH-3	53.920	TH-14	56.940
TH-4	56.130	TH-15	50.720
TH-5	56.660	TH-16	54.430
TH-6	55.730	TH-17	56.440
TH-7	56.500	TH-18	52.180
TH-8	57.280	TH-19	53.640
TH-9	54.100	TH-20	52.510
TH-10	59.220	TH-21	50.260
TH-11	58.440	TH-22	50.680

All readings taken in degrees F (C or F)

Figure 3-20.—Example field data sheet for thermotic survey.

When measurements are made to detect seepage paths, a reference location is chosen for one electrode. The reference electrode normally is placed where little or no seepage is expected. Areas of greater seepage will have a more negative electrical potential than the reference area, provided the positive terminal of the voltmeter is connected to the reference electrode. Such difference in potential can range up to a few hundred millivolts.

Polarization effects at the electrode and telluric currents can mask the streaming potential. However, short-term polarization effects are usually less than 2 millivolts in magnitude, and although telluric currents can result in much greater effects, they are identifiable as cyclical variations with 10- to 40-second periods. Detectable streaming potential must be greater than 25 millivolts. Usually the positive terminal of the voltmeter is connected to the reference electrode so that seepage areas are indicated by negative voltages.

When measurements are made on the reservoir bottom, seepage areas should be easily identifiable with one survey, provided the survey involves enough points to allow a reasonably detailed contour map to be drawn. On the reservoir bottom, the greater anomaly indicates the greater flow. When measurements are made where the electrodes do not physically contact the moving water, as in a survey downstream of a dam, several sets of readings are needed to define the voltage versus reservoir-head relationship. Because the electrodes in such a downstream survey are not in direct contact with the water, it cannot be assumed that the greater anomaly is associated with the greater seepage flow. A smaller seepage flow near the electrode can produce a stronger potential difference than a larger flow farther away. Instead, it should be assumed that the anomaly that is affected more, percentagewise, by reservoir fluctuations indicates the more important seepage path.

Each electrode of a permanent installation is wired separately to the reference electrode. Because the resistivity of the electrode and the earth materials (i.e., moisture content) can change, a permanent installation designed to monitor trends must be augmented with a resistivity survey. The same electrodes are then used to apply a voltage to the earth. Even though the magnitude of anomalous voltages may, while the resistivity changes, continue to indicate areas of seepage, it is not possible to use such voltages to indicate trends. This may be done by using Ohm's law and by monitoring the current. As voltage and resistivity drop, the current as a ratio of voltage over resistivity may actually increase, indicating an increase in seepage. More research must be done on the possibility of monitoring current to determine long-term seepage trends.

In their 1969 paper [59], Ogilvy, Ayed, and Bogoslovsley described a method for mapping the origins of seepage on the reservoir bottom. In their 1982 paper [16], Cooper, Koester, and Franklin described a method of delineating seepage paths outside of the reservoir. These two papers are perhaps the most definitive on electrical potential monitoring at dams, however, neither addresses the possibility of long-term monitoring. The monitoring of streaming potentials now appears to be a promising method of detecting seepage paths. Nevertheless, more work must be performed, particularly concerning long-term monitoring, before this promise can be realized.

Chapter IV

INTERNAL MOVEMENT MEASURING DEVICES

A. Usage and Types of Instruments

45. General.—Many internal movement measuring devices have been developed by various agencies and individuals. This chapter covers only those devices that are installed within the embankment, foundation, or abutment structures of a dam. Surface or external movement measuring devices are discussed in chapter V.

Determining the rate and amount of several types of movement in an earth dam is desirable. The most significant movements are classified as vertical, horizontal (translational), and rotational. Vertical movements, which indicate settlement of the embankment, are commonly the result of consolidation of foundation soils or of embankment materials. Horizontal, or translational, movements refer to movements of the embankment that are approximately perpendicular to the axis of the dam. They may take the form of the simple translational movement of the mass of the dam in a downstream direction caused by the horizontal force of the reservoir water pressure, or they may be caused by lateral spreading of the foundation soils or the lower portion of the embankment as a result of low shearing strength of the soils in either of those areas. Rotational movements, which can occur on either the downstream or the upstream slope of a dam, are usually the result of the low shearing strength of either the foundation or the embankment soils. In this case, a lower slope of an embankment moves outward with respect to the center of the embankment. The overall shape of the movement plane commonly approximates a circular arc in relatively homogeneous materials, but may occur along flat planes in embankments containing zones of different material properties.

The instruments installed to measure internal movements are installed for the life of a structure. Therefore, the devices must be easy to obtain and install, simple to operate, relatively corrosion resistant, durable, readily adaptable to the site conditions, and, of course, capable of yielding the information desired. The recording instruments must be simple, direct-reading, mechanical or electrical devices that can be used by relatively inexperienced personnel.

46. Types of Instruments.—The devices used to measure internal movements include several types of embankment settlement apparatus, inclinometers, borehole extensometers, shear strips, and radiosonde systems. Each type is discussed in detail in succeeding sections of this chapter, along with its advantages and limitations as perceived by USBR experience.

B. Currently Used Devices

47. Internal Vertical Movement Device.—a. ***Usage.***—An embankment settlement apparatus was developed by USBR personnel in the 1930's to record consolidation at 5- or 10-foot intervals in the vertical direction (height) in an embankment, total consolidation for an entire embankment, total settlement of the foundation material, and total settlement of individual measuring arms with respect to initial placement elevations. The IVM (internal vertical movement) device has not been installed in USBR dams recently because other instruments that are easier to install and monitor have been developed.

b. ***Advantages and Limitations.***—The advantages of devices like the IVM include the relatively accurate determination of consolidation of different levels of a foundation and embankment. Settlement plates, discussed in section 48, measure the total consolidation of all strata below the plate elevation; whereas, IVM devices measure the consolidation of each layer at vertical intervals corresponding to the interval at which crossarms are installed.

The limitations include the need for the devices to be installed during construction of the embankment because drill hole installation is not possible. As a result, these devices often get in the way of construction equipment, causing construction delays and possible damage to the device.

c. ***Description of Equipment.***—The IVM basically consists of vertical sections of 2-inch-diameter standard steel pipe jointed together. Horizontal crossarms consisting of 1.5-inch-diameter pipe or channel sections are installed at either 5- or 10-foot vertical intervals as the embankment is constructed (see figs. 4-1 and 4-2). The installation should continue to the top surface of the dam. When soil conditions necessitate, pipes are coated with protective paint before installation.

The first IVM system was installed in 1936 at Caballo Dam and is still operational. That device consists of 2- and 1.5-inch-diameter steel pipe, fittings, a latching plate, channel crossarms, U-bolts, pipe covers, oakum, burlap, wire, grout, concrete, and a measuring probe.

(1) *Pipe and Fittings.*—Standard 2- and 1.5-inch-diameter steel pipe with standard fittings is used. Pipe requiring threaded couplings is provided with standard tapered threads. Sufficient threads are provided on each pipe length to permit the lengths of pipe to butt within 1/16 inch when connected by a standard pipe coupling. All burred edges on the ends of the pipes must be removed before installation.

Steel, 5-pound channel crossarms and U-bolts are used at the crossarm and vertical pipe junctures. Details of their construction are shown on figure 4-1. All standard pipe and channel sections are painted with two coats of coal-tar epoxy paint in accordance with Federal Specification TT–P–86G before installation. Joints are coated with oakum and wrapped with burlap to keep soil out of the moveable joints.

(2) *Latching Plate.*—A latching plate assembly is installed at the bottom of the 2-inch-diameter riser pipe so that after readings are taken, the expanding latches on the measuring probe can be closed enabling the probe to be removed from the riser pipe. The latching plate assembly is also detailed on figure 4-1.

(3) *Measuring Probe.*—An approved embankment measuring probe, or torpedo, and a reading scale, tape, and other appurtenant items are required to measure the amount of settlement at each crossarm level. Figure 4-3 shows details of this device.

(4) *Backfill.*—Approved backfill consisting of select granular material, grout, and concrete is used for filling around the IVM as shown on figure 4-1.

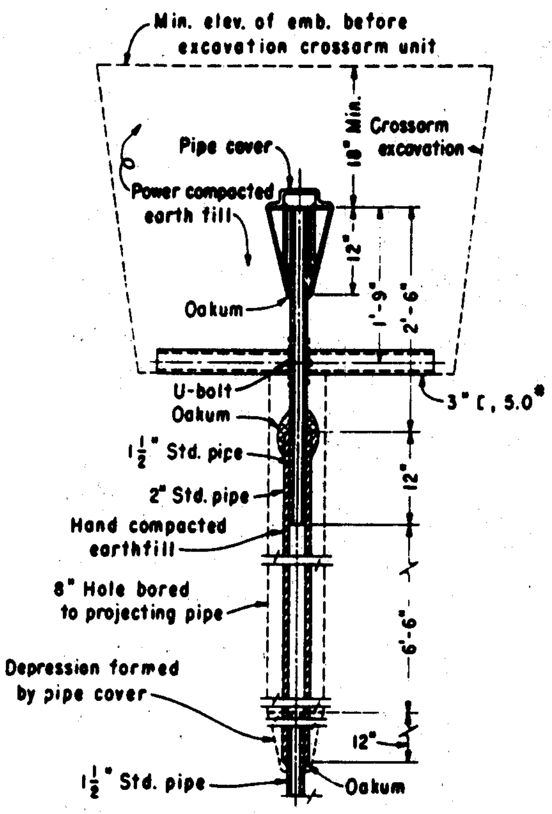
d. ***Installation.***—As shown on figure 4-1, the base pipe extension is installed in the foundation of the dam below the lowest planned crossarm level. Typically, crossarms are placed at 10-foot vertical intervals. The lowest crossarm is installed in a shallow trench. Backfilling is then accomplished and the embankment constructed to a level of 10 to 12 feet above the crossarm location where an excavation to the previous level is conducted. An additional 10 feet of riser pipe is then attached and another crossarm device added. The installation proceeds to the dam surface.

Original elevations at the various levels of the vertical movement device are obtained during the installation of each crossarm unit. Elevations are commonly determined, to an accuracy of 0.01 foot when the backfill placed around the unit is within approximately 12 inches of the top of the 1.5-inch-diameter pipe. Reference benchmarks must be located off the embankment. A complete set of readings is made on the entire existing installation each time an additional crossarm unit is installed. The final surface elevation is obtained on the surface of the top pipe in the embankment.

Maintaining the vertical alignment of the riser pipe is important. Record soil characteristics tests are made in the rolled embankment as each trench is excavated for its crossarm unit and in the tamped material as each trench is backfilled.

e. ***Monitoring Procedure.***—Monitoring is accomplished on a designated schedule by lowering the reading probe into the riser pipe and successively stopping at each crossarm location, starting with the uppermost crossarm. The probe is lowered just past the crossarm then lifted until the latches make contact with the crossarm device. The depth to that point from the top of the pipe is then recorded. Each crossarm is then measured in the same manner progressing downward. The probe may then be removed from the pipe by lowering it to the latching plate (which closes the probe) at the bottom of the pipe. The elevation of the top of the pipe must then be determined from an off-dam reference benchmark and the pipe cap replaced. The data are recorded on Field Data Form 7–1348 as shown on figure 4-4.

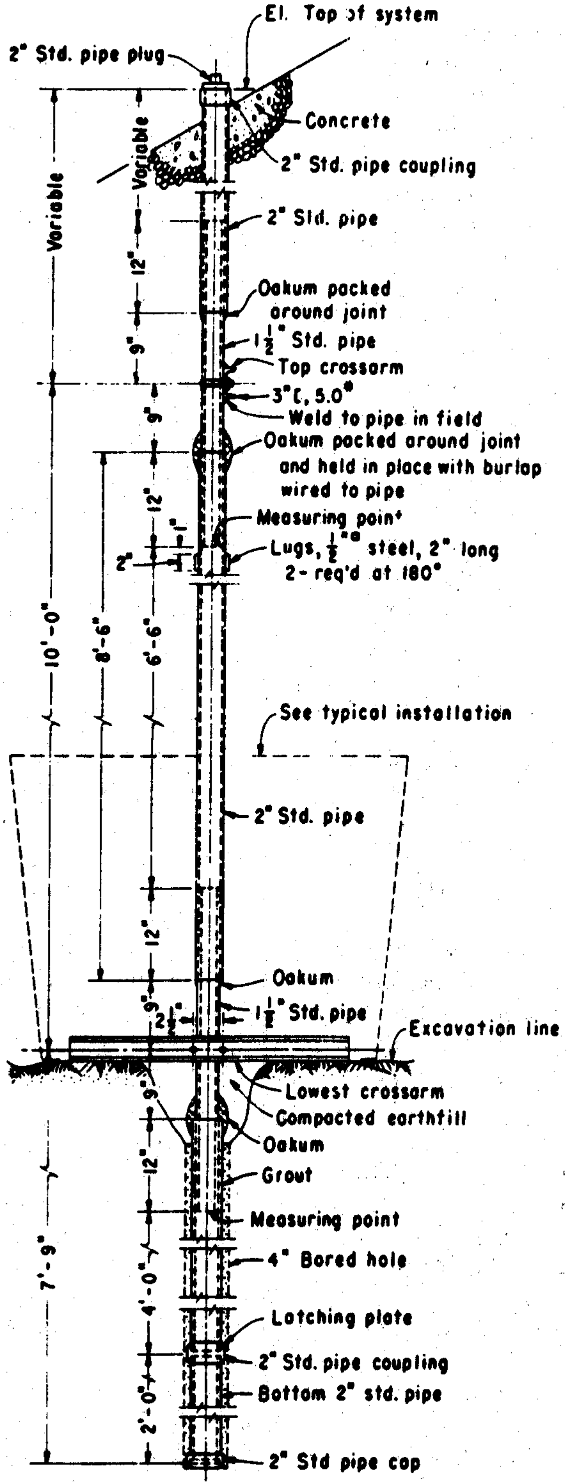
f. ***Maintenance.***—The measuring devices must be kept clean and free of grit. It is suggested that the measuring device be disassembled, as far as practicable, and either cleaned or flushed with clear water after each day's readings. The measuring tape should be carefully dried and inspected for kinks and breaks. An application of silicon grease on the tape will retard corrosion. If the pawls on the torpedo probe refuse to latch when the device reaches the latching assembly at the bottom of the riser pipe, a section of ½-inch pipe, 2 feet long or longer, can be slipped over the tape and lowered by wire into the installation until it rests on the probe. This added weight should latch the probe so that it can be removed. Some IVM devices become plugged with silt or corroded, necessitating periodic cleaning. Such cleaning can normally be accomplished by jetting with water under high pressure or through use of chimney brushes for pipe side wall cleaning.



TYPICAL INSTALLATION

NOTES

Determine elevations for all crossarm units to 0.01 foot when each new unit placed.



TYPICAL COMPLETED INSTALLATION

Figure 4-1.—Internal vertical movement device installation. 101-D-542

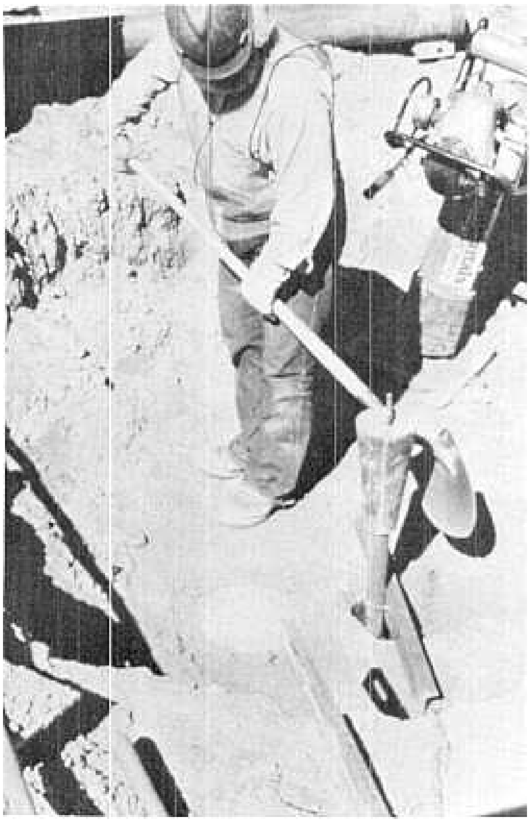


Figure 4-2.—Installation of internal vertical movement device. P801-D-81017.

g. *Data Processing and Review.*—The field data are transmitted to the Structural Behavior Branch where handling and processing proceeds as indicated in section 25. A plot of settlement versus time and of settlement with respect to different instrument points are created as shown on figure 4-5.

48. Foundation Baseplate.—a. *Usage.*—A foundation baseplate installation is intended to measure the consolidation in the foundation soils below a dam. The device is designed to separate the effects of consolidation from the total settlement of the embankment.

b. *Advantages and Limitations.*—The advantages of foundation baseplate installations are that they are readily site adaptable, rugged, and easy to install and read. The disadvantages include the fact that the devices yield a limited amount of information and some rusting and other maintenance problems often commonly occur on the inside of the riser pipes.

c. *Description of Equipment.*—The most common foundation baseplate unit consists of a baseplate section, an anchor crossarm section, and sections of 1.5- and 2-inch pipe. A typical installation is shown on figure 4-6.

The baseplate section consists of 5-pound steel channel to which two flat steel plates are welded. This channel is then bolted and welded to a length of 1.5-inch-diameter standard steel pipe. The unit is then nested in a section of 2-inch standard steel pipe anchored into the foundation. This 2-inch pipe extends to the ground surface. An anchor crossarm is attached to the 2-inch pipe 4 feet above the baseplate to measure the consolidation in the embankment. This entire apparatus is installed as the embankment is constructed. Readings are taken by lowering the reading probe into the pipe and reading the distance to the baseplate. The elevation of the top of the pipe is also determined.

d. *Variations of Baseplate Device.*—Other versions of the baseplate settlement apparatus have been used. One version involves simply burying a baseplate, whose exact elevation and horizontal location are known, in the foundation or in the embankment. After the embankment is constructed over the plate, a hole is drilled down to the plate and a plastic pipe of known length is set in the hole. A record of the elevation change can

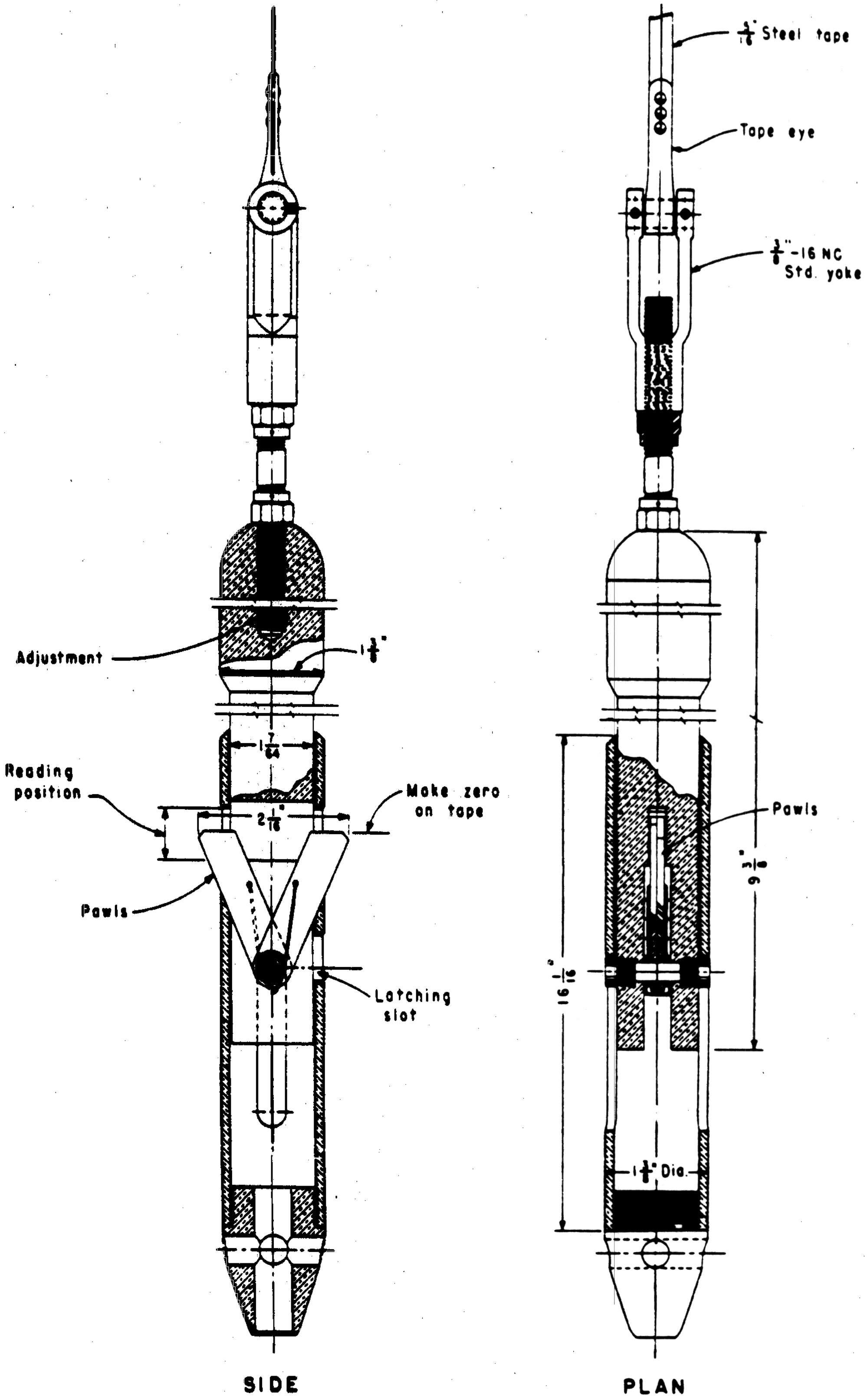
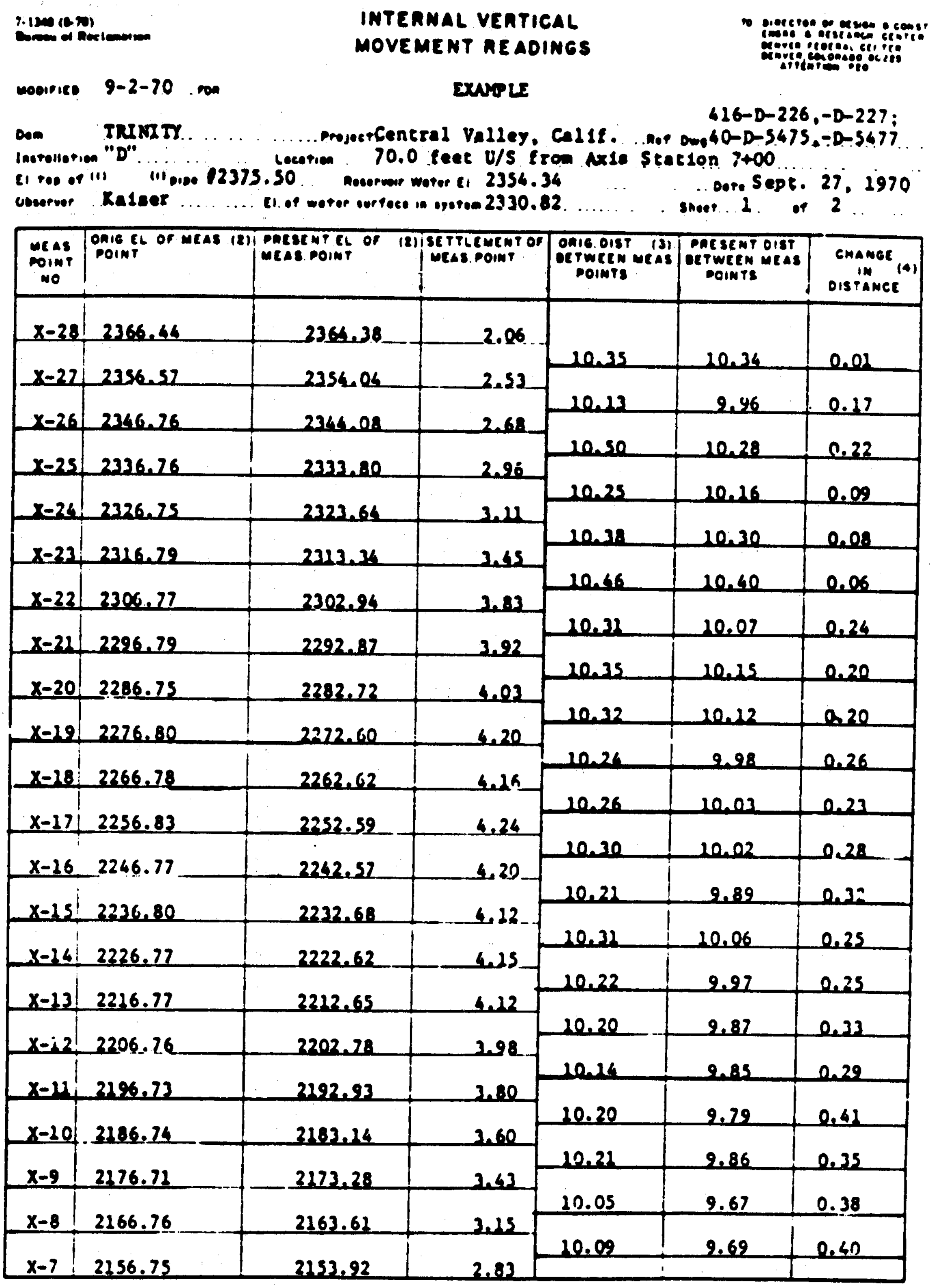


Figure 4-3.—Vertical movement measuring probe (torpedo). 101-D-543.



7-1348 (8-70)
Bureau of Reclamation

INTERNAL VERTICAL MOVEMENT READINGS

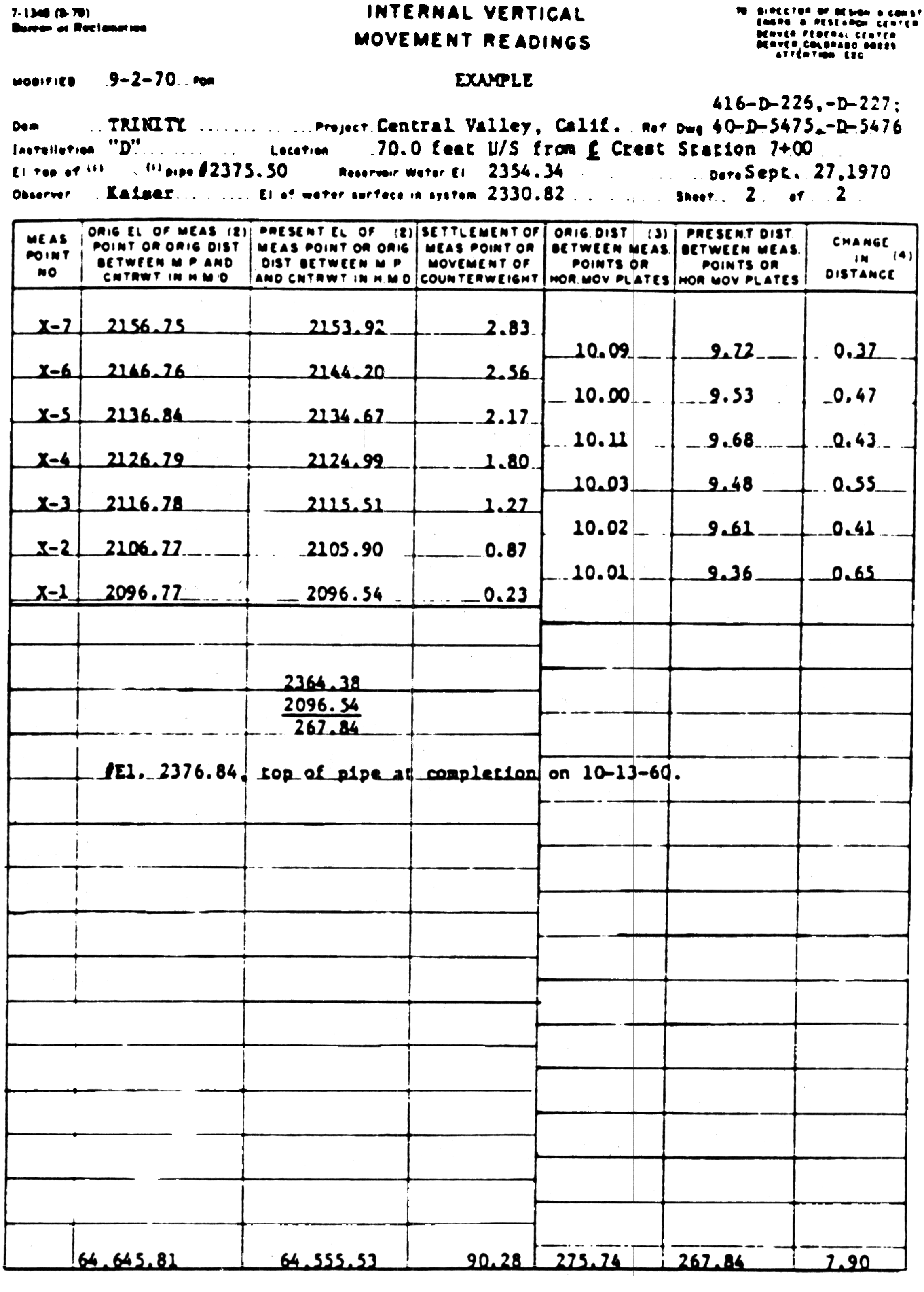
TO DIRECTOR OF DESIGN & CONST
ENGRG & RESEARCH CENTER
DENVER FEDERAL CENTER
DENVER COLORADO 80225
ATTENTION 220

MODIFIED 9-2-70 FOR EXAMPLE

Dam TRINITY Project Central Valley, Calif. Ref Dwg 416-D-226,-D-227; 40-D-5475,-D-5477
Installation "D" Location 70.0 feet U/S from Axis Station 7+00
El Top of (1) (1) pipe #2375.50 Reservoir Water El 2354.34 Date Sept. 27, 1970
Observer Kaiser El. of water surface in system 2330.82 Sheet 1 of 2

MEAS POINT NO	ORIG EL OF MEAS (2) POINT	PRESENT EL OF (2) MEAS POINT	SETTLEMENT OF MEAS POINT	ORIG DIST (3) BETWEEN MEAS POINTS	PRESENT DIST BETWEEN MEAS POINTS	CHANGE IN (4) DISTANCE
X-28	2366.44	2364.38	2.06			
				10.35	10.34	0.01
X-27	2356.57	2354.04	2.53			
				10.13	9.96	0.17
X-26	2346.76	2344.08	2.68			
				10.50	10.28	0.22
X-25	2336.76	2333.80	2.96			
				10.25	10.16	0.09
X-24	2326.75	2323.64	3.11			
				10.38	10.30	0.08
X-23	2316.79	2313.34	3.45			
				10.46	10.40	0.06
X-22	2306.77	2302.94	3.83			
				10.31	10.07	0.24
X-21	2296.79	2292.87	3.92			
				10.35	10.15	0.20
X-20	2286.75	2282.72	4.03			
				10.32	10.12	0.20
X-19	2276.80	2272.60	4.20			
				10.24	9.98	0.26
X-18	2266.78	2262.62	4.16			
				10.26	10.03	0.23
X-17	2256.83	2252.59	4.24			
				10.30	10.02	0.28
X-16	2246.77	2242.57	4.20			
				10.21	9.89	0.32
X-15	2236.80	2232.68	4.12			
				10.31	10.06	0.25
X-14	2226.77	2222.62	4.15			
				10.22	9.97	0.25
X-13	2216.77	2212.65	4.12			
				10.20	9.87	0.33
X-12	2206.76	2202.78	3.98			
				10.14	9.85	0.29
X-11	2196.73	2192.93	3.80			
				10.20	9.79	0.41
X-10	2186.74	2183.14	3.60			
				10.21	9.86	0.35
X-9	2176.71	2173.28	3.43			
				10.05	9.67	0.38
X-8	2166.76	2163.61	3.15			
				10.09	9.69	0.40
X-7	2156.75	2153.92	2.83			

Figure 4-4.—Typical completed Form 7-1348, Internal Vertical Movement Readings. (Sheet 1 of 2). 101-D-598



7-1348 (9-70)
Bureau of Reclamation

INTERNAL VERTICAL MOVEMENT READINGS

TO DIRECTOR OF DESIGN & CONST
ENGRG & RESEARCH CENTER
DENVER FEDERAL CENTER
DENVER COLORADO 80225
ATTENTION [illegible]

MODIFIED 9-2-70 FOR EXAMPLE

Dam TRINITY Project Central Valley, Calif. Ref Dwg 416-D-226,-D-227; 40-D-5475,-D-5476
Installation "D" Location 70.0 feet U/S from ℄ Crest Station 7+00
El top of (1) , (1) pipe #2375.50 Reservoir Water El 2354.34 Date Sept. 27,1970
Observer Kaiser El of water surface in system 2330.82 Sheet 2 of 2

MEAS POINT NO	ORIG EL OF MEAS (2) POINT OR ORIG DIST BETWEEN M P AND CNTRWT IN H M D	PRESENT EL OF (2) MEAS POINT OR ORIG DIST BETWEEN M P AND CNTRWT IN H M D	SETTLEMENT OF MEAS POINT OR MOVEMENT OF COUNTERWEIGHT	ORIG. DIST (3) BETWEEN MEAS. POINTS OR HOR. MOV PLATES	PRESENT DIST BETWEEN MEAS. POINTS OR HOR MOV PLATES	CHANGE IN (4) DISTANCE
X-7	2156.75	2153.92	2.83			
				10.09	9.72	0.37
X-6	2146.76	2144.20	2.56			
				10.00	9.53	0.47
X-5	2136.84	2134.67	2.17			
				10.11	9.68	0.43
X-4	2126.79	2124.99	1.80			
				10.03	9.48	0.55
X-3	2116.78	2115.51	1.27			
				10.02	9.61	0.41
X-2	2106.77	2105.90	0.87			
				10.01	9.36	0.65
X-1	2096.77	2096.54	0.23			
		2364.38 2096.54 267.84				
	64,645.81	64,555.53	90.28	275.74	267.84	7.90

#El. 2376.84, top of pipe at completion on 10-13-60.

Figure 4-4.—Typical completed Form 7-1348, Internal Vertical Movement Readings. (Sheet 2 of 2). 101-D-599

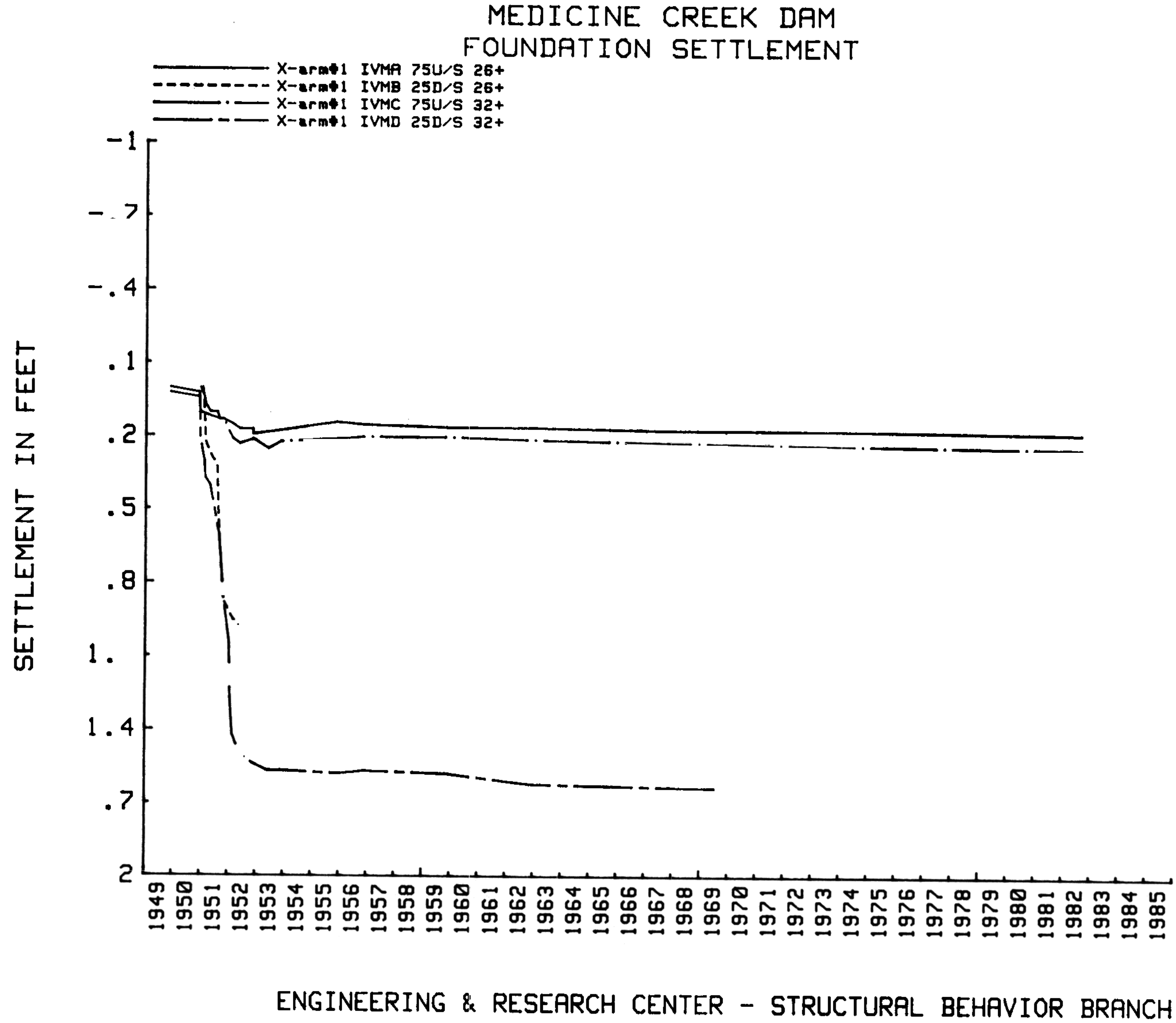


Figure 4-5.—Example plot of settlement data measured by vertical internal movement device.

be made by surveying the top of the pipe. Although this method of installation eliminates the problems caused by interference with construction equipment, the drilling after construction may be costly and hazardous to the embankment.

A variation of this type of installation involves affixing one end of a pipe to the baseplate when the baseplate is set and adding sections to the pipe as embankment construction proceeds. However, there is some friction on the pipe from the downward movement of the embankment. An attempt to eliminate this friction led to another variation of baseplate device in which two pipes are set, with one pipe inside the other. The outside pipe is subject to downward skin friction, but only the inside pipe is observed for elevation changes in the baseplate.

e. ***Monitoring Procedure.***—Baseplate settlement devices are monitored at prescribed intervals. Each type of installation requires accurate determination of the elevation of the top of the measurement pipe using a benchmark reference point located off the dam. The baseplate installation illustrated on figure 4-6 also requires lowering a probe into the 2-inch pipe and measuring the elevation of the 1.5-inch section of the foundation level. This operation is identical to the method used for the IVM device described in section 38. Data are recorded on Field Data Form 7–1359, as shown on figure 4-7.

f. ***Data Processing and Review.***—The Field Data Forms should be transmitted to the Structural Behavior Branch where data processing and reviews are conducted as described in section 25. A plot of settlement

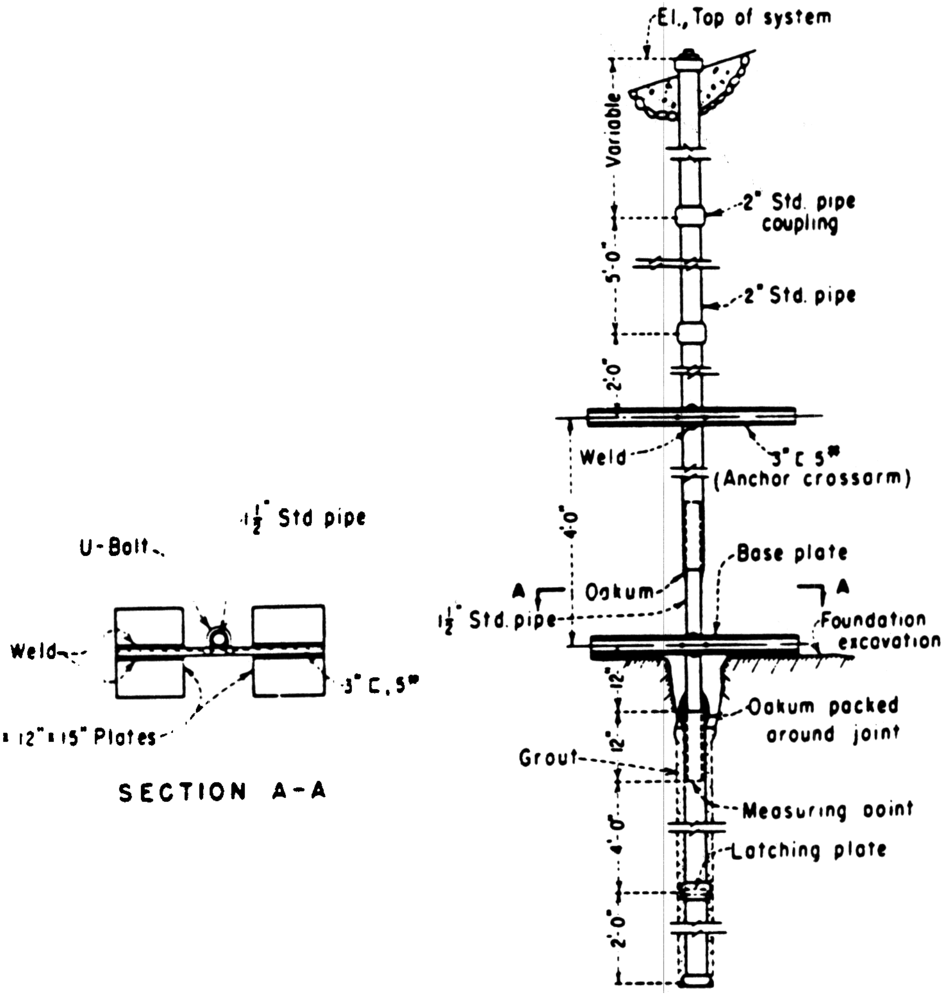


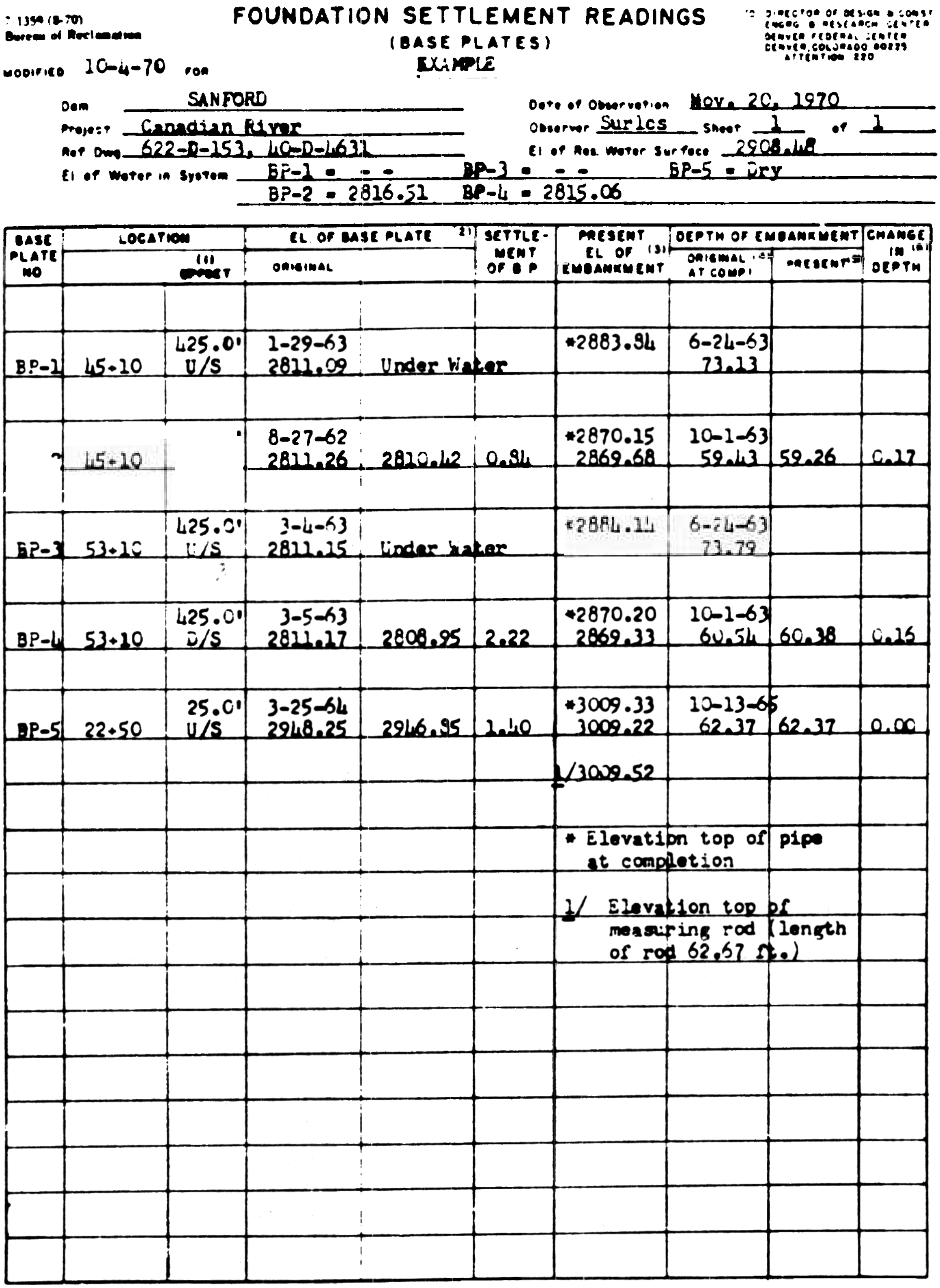
Figure 4-6.—Foundation baseplate installation. 101–D–318

at individual locations versus time and at several relative locations at the dam are prepared as shown on figure 4-8.

49. Pneumatic Settlement Sensor.—a. ***Usage.***—PSS (pneumatic settlement sensors) operate on the same principle as pneumatic piezometers. They are used to continuously monitor the difference in elevation between the sensor unit and its reservoir by means of a water column. The sensor unit may be installed in the dam foundation or anywhere in the embankment, and the liquid reservoir and readout area are normally located on the downstream slope of the dam.

Water pressure transmitted from the reservoir to the sensor by a hydraulic (water-filled) tube bundle is automatically balanced during readout by an opposing pneumatic pressure. A change in the elevation of the sensor is then reflected by a change in pneumatic pressure required to balance the hydraulic pressure. A typical sensor is shown on figure 4-9.

b. ***Advantages and Limitations.***—Pneumatic settlement sensors have several advantages over certain other devices: The level of the sensor tubes and the readout terminal are relatively independent of each other, and the sensors may be placed in the same trenches with closed system piezometers at little extra expense. Limitations include a relatively long reading time and the necessity for determining the elevation of the terminal reservoir for each set of readings. The USBR has had limited experience with these devices, and some accuracy problems have been experienced with installation and, in taking readings, some of which have led to very erroneous data. A potential problem is the freezing of the liquid reservoirs, unless they are heated or an ethanol, glycol, methanol mix is used.



7-1359 (8-70)
Bureau of Reclamation

FOUNDATION SETTLEMENT READINGS

(BASE PLATES)

TO DIRECTOR OF DESIGN & CONST
ENGRG & RESEARCH CENTER
DENVER FEDERAL CENTER
DENVER, COLORADO 80225
ATTENTION 220

MODIFIED 10-4-70 FOR EXAMPLE

Dam SANFORD
Project Canadian River
Ref Dwg 622-D-153, 40-D-4631
Date of Observation Nov. 20, 1970
Observer Surlcs Sheet 1 of 1
El of Res. Water Surface 2908.48
El of Water in System BP-1 = - - BP-3 = - - BP-5 = Dry
BP-2 = 2816.51 BP-4 = 2815.06

BASE PLATE NO	LOCATION	(1) OFFSET	EL. OF BASE PLATE (2) ORIGINAL		SETTLEMENT OF B P	PRESENT EL OF EMBANKMENT (3)	DEPTH OF EMBANKMENT ORIGINAL AT COMPL (4)	PRESENT (5)	CHANGE IN DEPTH (6)
BP-1	45+10	425.0' U/S	1-29-63 2811.09	Under Water		*2883.84	6-24-63 73.13		
[illegible]	45+10		8-27-62 2811.26	2810.42	0.84	*2870.15 2869.68	10-1-63 59.43	59.26	0.17
BP-3	53+10	425.0' U/S	3-4-63 2811.15	Under Water		*2884.14	6-24-63 73.79		
BP-4	53+10	425.0' D/S	3-5-63 2811.17	2808.95	2.22	*2870.20 2869.33	10-1-63 60.54	60.38	0.16
BP-5	22+50	25.0' U/S	3-25-64 2948.25	2946.95	1.40	*3009.33 3009.22	10-13-65 62.37	62.37	0.00
						1/3009.52			

* Elevation top of pipe at completion

1/ Elevation top of measuring rod (length of rod 62.67 ft.)

Figure 4-7.—Typical completed Form 7-1359, Foundation Settlement Readings. 101-D-601

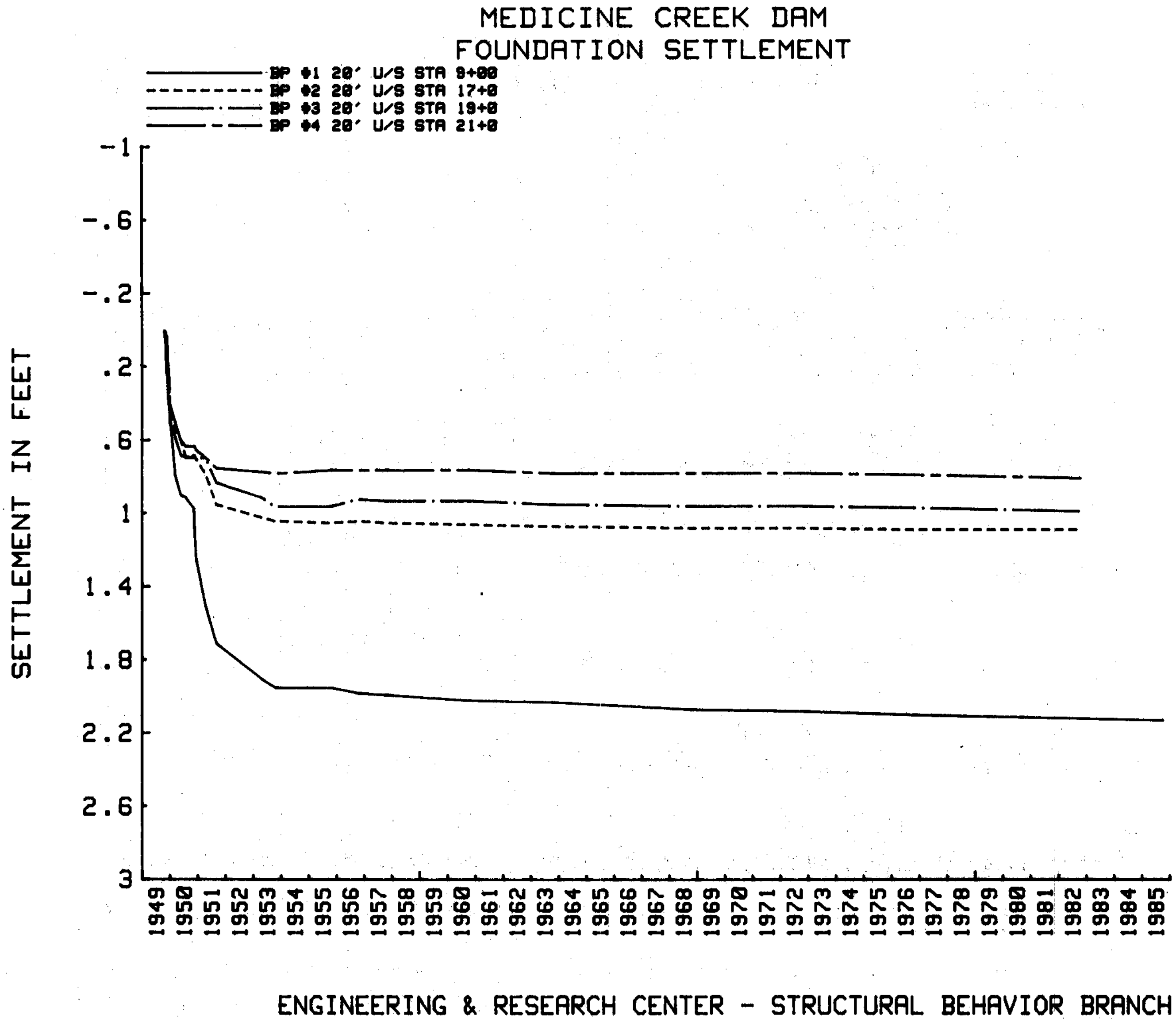


Figure 4-8.—Example plot of settlement data measured by foundation baseplate device.

c. ***Description of Equipment.***—PSS installations consist of a sensor assembly, tubing bundle, tubing bundle terminal assembly, portable pneumatic pressure indicator, pneumatic terminal panel, and backfill. Specifications for the sensor assembly are in Specification EDI-21 (app. A). The remainder of the items used in a PSS installation are identical to those described in section 31.

d. ***Installation.***—Pneumatic settlement sensors and appurtenant devices should be installed in the same manner as pneumatic piezometers (described in section 31), with the exception that the trench excavated into the embankment should have an upward slope of approximately 1 percent from the instrument farthest from the riser pipe. During installation of the settlement sensor, it is very important to prevent water loss from the water column. This water loss will create erroneous readings later. During installation each tubing line should have a slight rise from the sensor to the reservoir to naturally de-air the tubes. The liquid used in the water column must have a low thermal coefficient to compensate for temperature changes and must be deaired to remove all gas bubbles.

e. ***Monitoring Procedure.***—PSS devices should be monitored on a prescribed schedule. The monitoring procedure begins with the accurate determination of the elevation of the gauge on the terminal reservoir. Pressure readings should then be obtained by transmitting compressed air from the portable pneumatic pressure indicator or terminal panel through the tubing bundle to the sensor unit. The water pressure in the

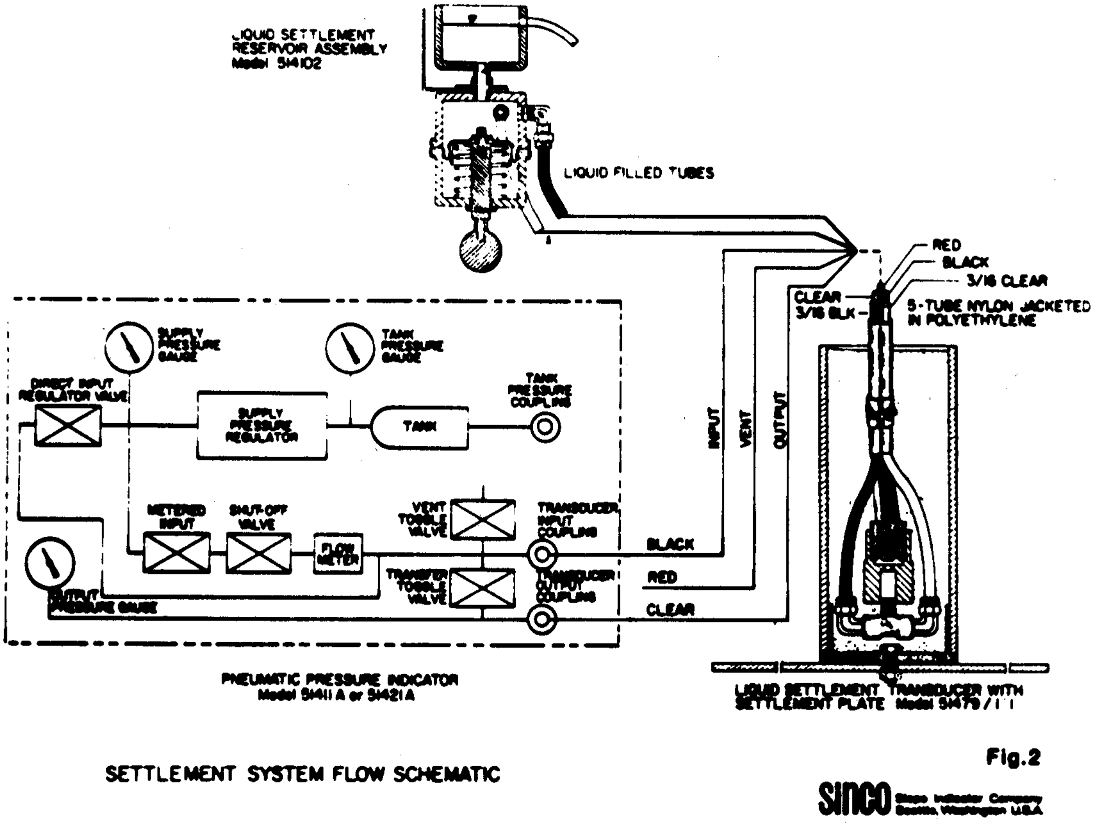


Figure 4-9.—Typical pneumatic settlement sensor.

unit is then balanced with the compressed air across a nonmetallic diaphragm, which vents excess air pressure to the atmosphere through a vent tube. A slight, continuous flow of air is required to operate the device. The flow controllers on the pneumatic readout units must be of high quality to allow accurate measurements of the flow being applied at the readout unit. If the units do not have this type of flow controller, the extra gas flow causes erroneous data.

f. ***Data Processing and Review.***—The pressure data are recorded in pounds of pressure per square inch on the field data form, as shown on figure 4-10. The pressure is converted to actual sensor elevations and transmitted to the Structural Behavior Branch for processing and review as discussed in section 25. A settlement plot is then prepared as shown on figure 4-11.

50. Vibrating-Wire Settlement Sensor.—a. ***Usage.***—The VWSS (Vibrating-wire settlement sensor) is a relatively recent development. Early models used mercury, but current models do not. None have yet been used by the USBR, but an installation at Davis Creek Dam[1] is planned. VWSS devices monitor the difference in elevation between a sensor and its reservoir located in a terminal well. The water pressure is transmitted between the sensor and its reservoir via hydraulic tube bundles as for the pneumatic settlement sensor discussed in section 49. The hydraulic pressure difference created by a change in the elevation of the sensor is measured by an electrical transducer that transforms piezometric pressures into the resonant frequencies of a vibrating wire and transmits these frequencies to a readout display unit. The readout unit is identical to the unit discussed in section 32 for vibrating-wire piezometers.

b. ***Advantages and Disadvantages.***—The vibrating-wire settlement sensor device is believed to combine the more desirable characteristics of both the vibrating-wire piezometer and the pneumatic settlement sensor. The principal advantages are ease and accuracy of reading. As previously described in section 49, one problem with the pneumatic settlement sensor is the regulating of the gas flow causing erroneous data. This problem

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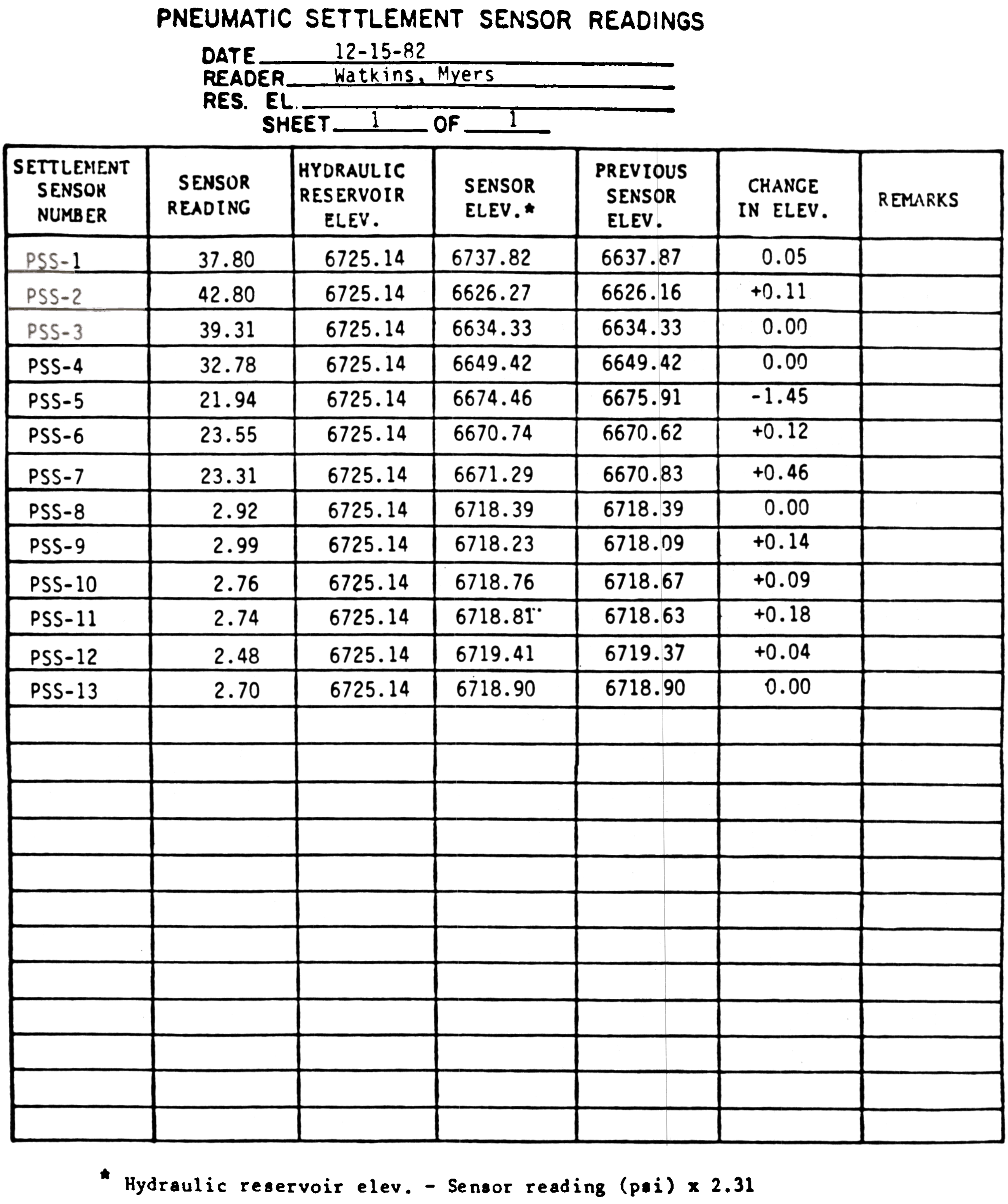
[1] Davis Creek Dam is to be a homogeneous earthfill dam, 153 feet high and 2,900 feet long, located on a tributary to Davis Creek in Valley County, Nebraska.



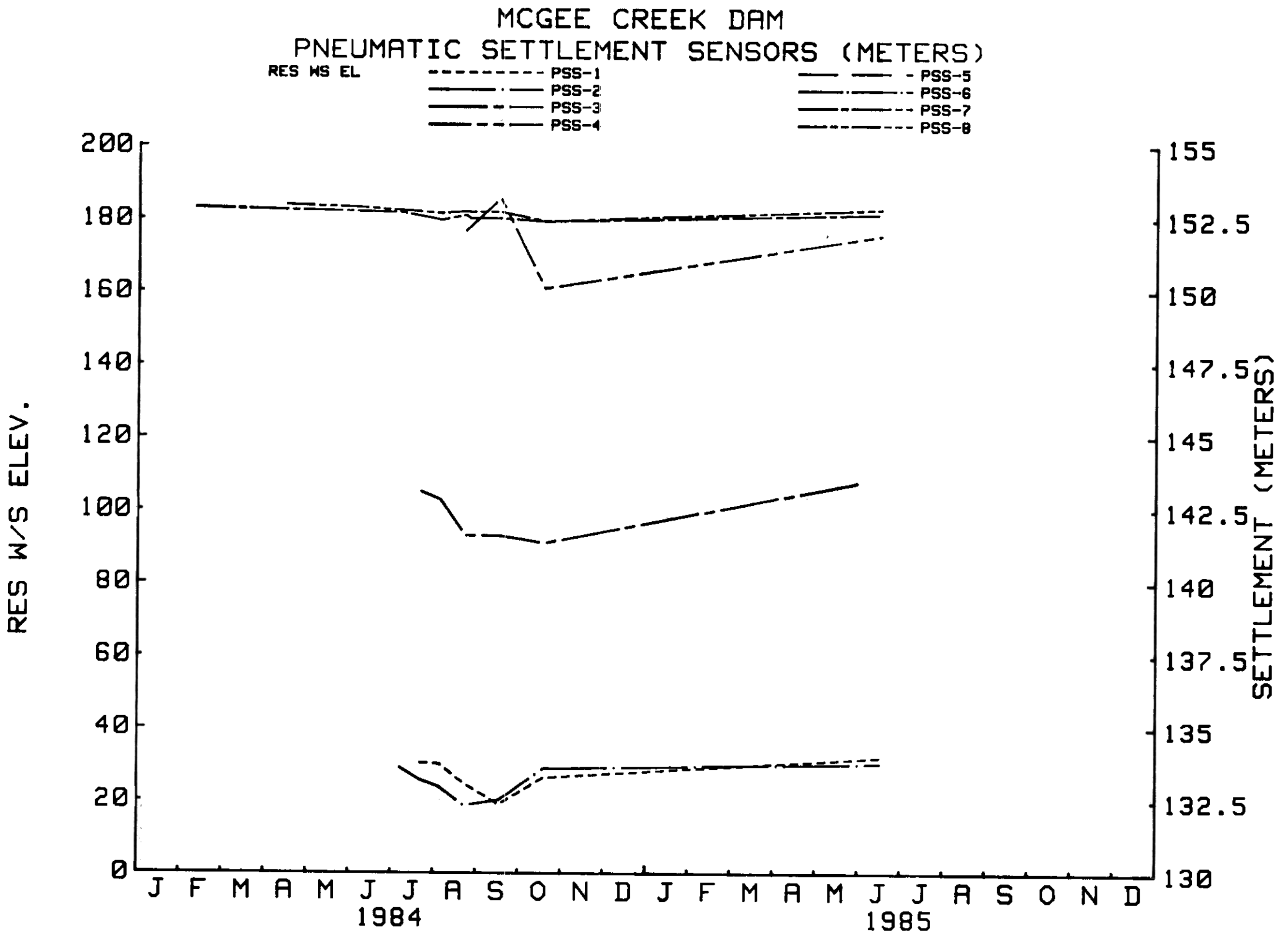
PNEUMATIC SETTLEMENT SENSOR READINGS

DATE 12-15-82
READER Watkins, Myers
RES. EL.
SHEET 1 OF 1

SETTLEMENT SENSOR NUMBER	SENSOR READING	HYDRAULIC RESERVOIR ELEV.	SENSOR ELEV.*	PREVIOUS SENSOR ELEV.	CHANGE IN ELEV.	REMARKS
PSS-1	37.80	6725.14	6737.82	6637.87	0.05	
PSS-2	42.80	6725.14	6626.27	6626.16	+0.11	
PSS-3	39.31	6725.14	6634.33	6634.33	0.00	
PSS-4	32.78	6725.14	6649.42	6649.42	0.00	
PSS-5	21.94	6725.14	6674.46	6675.91	-1.45	
PSS-6	23.55	6725.14	6670.74	6670.62	+0.12	
PSS-7	23.31	6725.14	6671.29	6670.83	+0.46	
PSS-8	2.92	6725.14	6718.39	6718.39	0.00	
PSS-9	2.99	6725.14	6718.23	6718.09	+0.14	
PSS-10	2.76	6725.14	6718.76	6718.67	+0.09	
PSS-11	2.74	6725.14	6718.81	6718.63	+0.18	
PSS-12	2.48	6725.14	6719.41	6719.37	+0.04	
PSS-13	2.70	6725.14	6718.90	6718.90	0.00	

* Hydraulic reservoir elev. - Sensor reading (psi) x 2.31

Figure 4-10.—Example data sheet for pneumatic settlement sensor readings.



ENGINEERING & RESEARCH CENTER - STRUCTURAL BEHAVIOR BRANCH

Figure 4-11.—Example plot of settlement data measured by pneumatic settlement sensor.

does not exist with the vibrating-wire settlement sensor. However, the VWSS manufactured by Geokon, Inc., has been modified based on USBR experience for more efficient and reliable operation. The modification consists of using two hydraulic tubes, rather than one, to flush the system for cleaning or for de-airing of the hydraulic system; using ¼-inch-diameter polypropylene tubes rather than ⅛-inch-diameter nylon composition tubes; using a glycol solution rather than mercury; and installing the sensor in a sand envelope rather than in a concrete block. These modifications should result in more accurate readings, better maintenance, and longer life of the device.

c. ***Description of Equipment.***—As shown on figure 4-12, the VWSS device consists of a settlement sensor unit, hydraulic tubing bundles, tubing bundle terminal, and sand backfill. In addition, a vibrating-wire readout device and a portable flushing system are required. Specification EDI–22 (app. A) covers the settlement sensor unit, and Specification EDI–5 (app. A), previously cited for pneumatic piezometers in section 31, are valid for the tubing, tubing bundle assemblies, and backfilling. The vibrating-wire readout unit should be as previously specified in section 32. Each settlement sensor is provided with a hydraulic reservoir (in addition to future connections to a common reservoir) so that readings may be taken during construction and before final installation of the terminal house. The common reservoir, which is designed to prevent evaporation, should be affixed to the control house wall.

d. ***Installation.***—VWSS devices are installed in a foundation or embankment by drilling or excavating a small (8- to 10-inch-diameter) hole 1 to 1.5 feet deep. The instrument is placed in the hole and its precise elevation determined. All hydraulic and electrical systems are checked for proper operation and the hole

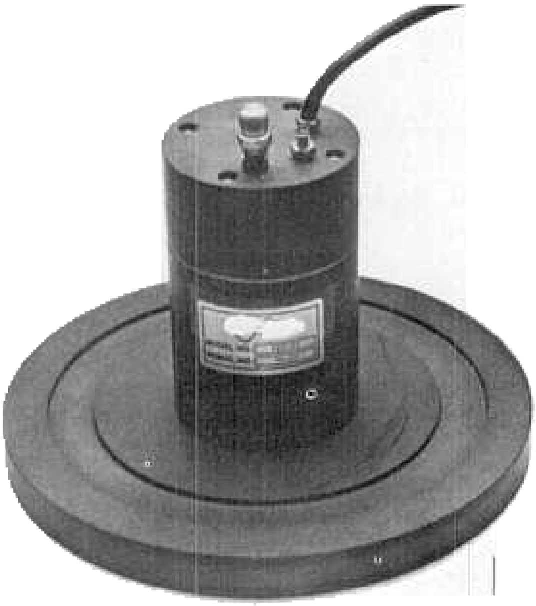


Figure 4-12.—Vibrating-wire settlement sensor. P801-D-81018.

backfilled with concrete sand. Only minor tamping by hand is allowed, and special care is taken not to kink or create sharp bends in the hydraulic tubes or electrical cable. The tube and cable are then placed into an adjacent trench and directed toward the terminal house. Backfilling of the trench or trenches containing the tube bundles should be as described in section 31.

The liquid used to fill the hydraulic leads should have a specific gravity of 1.0 so that adjusting the readout valves is unnecessary. This liquid is a controlled mixture of ethylene glycol, methanol, and water. The mixing ratio (by volume) is 655 units ethylene glycol to 345 units methanol, which produces an antifreeze with a specific gravity of 1.0. This blend is then mixed with 40 percent water to provide freezing protection to about −52 °C. (−61.6°F.) The use of mercury is no longer allowed in the sensor system.

e. ***Monitoring Procedure.***—The settlement sensors should be read on a predetermined schedule. The readout device electrical leads are connected to the electrical cable for a sensor before the readout device is turned on and a digital reading obtained. The reading is repeated, and if unchanged, recorded on the field data sheet. A calibration sheet is then used to convert the readings to elevation change. The actual elevation of the common reservoir must be determined for each set of readings if the reservoir or the control house is subject to elevation change.

f. ***Data Processing and Review.***—The field data forms are to be transmitted to the Structural Behavior Branch where the data will be processed and analyzed as discussed in section 25. The data should be plotted as described in section 47.

51. Inclinometer (Normal Installation).—a. *Usage.*—Inclinometers are used to measure lateral ground movements in abutments, foundations, or embankments, and consolidation-induced settlement in embankments and foundations. Measuring settlement by the vertical movement of inclinometer casings has now largely replaced the earlier method using IVM devices. Thus, the same installation now measures settlement and lateral movement.

Inclinometer casing may be installed with slip joints as embankment construction progresses, providing the opportunity for settlement measurements, or it may be installed in drillholes with butt joints in abutments or completed embankments if no significant settlement is anticipated.

b. ***Advantages and Limitations.***—Inclinometer installations have proved they can give reliable and accurate information for years provided proper installation, maintenance, and monitoring procedures are used.

The only significant limitation of this type of instrumentation is that a significant degree of specialized training is required for personnel reading the devices. Such personnel must be trained in the proper care and operation of the equipment. They must be able to recognize erroneous or anomalous data while in the field.

c. ***Description of Equipment.***—Inclinometer systems consist of special casings, casing couplings, inclinometer probe, cable, readout unit, settlement probe, data transmittal system, backfill material, and a surface protective pipe with a locking cap.

(1) *Casing.*—Aluminum (epoxy-coated), anodized aluminum, and plastic casings are available in various sizes. Selecting the proper size casing must include consideration of drill hole size (in a drill hole installation) and the intended use of the inclinometer. The inclinometer casing installation is the most critical factor in the entire inclinometer system. For example, if the casing is to monitor a landslide that is actively moving, installing a small diameter casing is not practical. When movement occurs, the smaller the casing diameter, the sooner the casing will close, and the installation, along with the possibility of additional data, will be lost. The drill hole diameter should be as large as practical to facilitate grouting around the outside of the casing. For example, when installing the largest casing size (3.38-inch o.d.), a minimum 6-inch-diameter drill hole should be provided.

Aluminum casing with slip joints should be used in embankment installations; whereas, either plastic or aluminum casing with standard butt couplings may be used in drill hole installations. Plastic casing is not desirable for embankment installation principally because it can warp from extended exposure to hot sunlight. Plastic casing installations often experience problems when the data are being taken: The casing grooves tend to spiral more than those in aluminum casings. Also, plastic casings do not allow the wheel assemblies on the inclinometer probes to track, or remain in the grooves of the casing, as well as aluminum casings. The USBR has experienced much better overall results using aluminum casing rather than plastic casing and now generally favors aluminum casing. Anodized aluminum casing has proved to work best in a wide range of installations. The advantages of this casing over epoxy-coated aluminum are (1) during installation the epoxy easily is chipped off leaving the casing exposed to weather; (2) during data collection, the epoxy is rubbed off by the wheels of the measuring probes, sometimes stopping the probes from being lowered down the hole; and (3) the epoxy coating is more expensive. Aluminum casing is available in either 5- or 10-foot lengths. See Specification EDI-23 (app. A) for details of casing and couplings.

(2) *Casing Couplings.*—Two common types of coupling are available: slip-type aluminum couplings and standard butt couplings.

For use in embankments, 12- to 24-inches long slip-type aluminum couplings are available. Because embankment installations are used for settlement observations, the coupling selected should be long enough to provide for the settlement anticipated. Slip-type joints are usually used only in embankments, but if settlement is anticipated below a dam, slip joints may be used in the foundation.

Standard 6-inch-long couplings are used for butt joint drill hole installations. These couplings are attached to the casing by means of pop rivets at 90° points around the casing. The grooves in the casing must be aligned when the couplings are attached. Both types of couplings are sold by the casing manufacturers.

(3) *Inclinometer Probe.*—The inclinometer probe measures angles of inclination from vertical in two planes oriented at 90° (orthogonal) to each other. Some servo-accelerometers can measure inclination angles up to 90° over the 2-foot-long measuring distance; however, the commonly used probe measures angles up to 30°. Spring-loaded wheels keep the probe within the grooves in the casing. Specification EDI-24 (app. A) covers the probe and the cable. The cable must be long enough to take measurements in the deepest casing on the project. The markings on the cable are at 1-foot intervals to allow measurement of the depth for each reading.

(4) *Readout Unit and Data Transmittal System.*—A simple readout unit visually displays the reading of one accelerometer and, by switching the selector switch, the reading of the second accelerometer. Both readings are recorded on the data sheet, along with the depth measurement. The cassette recorder unit is a self-contained, portable, waterproof unit with a rechargeable battery. Inclinometer data are visually displayed to the operator and simultaneously recorded on the cassette recorder tape. The date, inclinometer number, and depth of reading are also automatically recorded on the tape.

The data transmittal system consists of a data selector switch and leads interfacing the cassette recorder with a CRT (cathode ray tube) terminal. An additional lead interfaces the selector switch with a telephone modem to transport the data to the USBR's centralized computer system at the Structural Behavior Branch office. All existing equipment operates at the 300-baud rate. Specification EDI-25 (app. A) covers this equipment.

(5) *Settlement Probe.*—The preferred type of settlement probe is shown on figure 4-3. A survey tape or chain is required to fit the casing length. This chain must be marked to the nearest 0.01 foot for its entire length.

(6) *Surface Protective Pipe.*—A 1-foot-diameter steel (schedule 40) pipe several feet in length with a thick steel lid is required to provide protection and security for the top of the casing. The lid is attached by a hinge on one side with a hasp and eye arrangement to accommodate a padlock on the other side. The protective pipe should be installed to an elevation 1 to 2 inches above the top of the inclinometer casing.

(7) *Backfill.*—An inclinometer installation constructed with the embankment requires no special backfill. The soil used for the embankment is compacted carefully around the casing. Inclinometer casings installed in drill holes are backfilled with pumped sand-cement grout.

d. ***Installation.***—Inclinometer casings must provide reliable orientation for the inclinometer probe. Therefore, proper installation procedures must be observed. Installation locations are selected based on subsurface conditions, topography, and the depth of anticipated movements.

The casing may be placed in almost any stable drill hole large enough to contain the casing and backfill. If a hole larger than 6-inch diameter is used, spacers should be used around the inclinometer casing to ensure proper casing location and orientation. Some problems have been experienced with corrosion of aluminum casing when the casing has been exposed to alkaline soil, corrosive ground water, or certain grouts. Coating the aluminum with epoxy has helped minimize this problem, but epoxy can be scratched or removed during installation. Flushing the casing with water after grouting has also helped minimize corrosion. Anodized aluminum has been found to perform satisfactorily in most installations.

To save drilling costs, the casing is commonly installed in conjunction with subsurface test boring and sampling programs. Inclinometer casing is normally delivered in 5- or 10-foot lengths (10-foot lengths are preferable). While drilling and sampling is being completed, casing sections may be preassembled in 10-, 20-, or 30-foot segments to expedite the downhole assembly work. The casing sections are joined with couplings and sealed to prevent intrusion of grout or backfill materials. Depending on the application and type of casing, solvent cements, tape, or other sealers may be used. For plastic casing, a special alignment key is inserted into the grooves of each section to aid alignment. For added strength and to help prevent twisting and groove misalignment, pop-rivets are used on both plastic and aluminum casing to reinforce the couplings.

One method of grouting involves the use of one-way valves, which are fitted to the bottom section of the casing to facilitate grouting through the casing using drill rods. Once the casing is in place, hollow drill rods are lowered into the casing and attached to the nipple on the one-way grouting valve. The problems with this method of grouting are:

(1) As the drill rods are lowered, they may cut into the sidewall of the casing and damage the grooves.

(2) After grouting is complete, a large volume of water must be pumped down the drill rods to remove the remaining grout from the rods. If this is not accomplished, the grout will spray the inside of the casing and adhere to it, creating roughness or plugging the grooves.

During the insertion of the casing sections, clamps may be used at the top of the hole to prevent the lower casing sections from falling to the bottom of the hole. For very deep installations, a tension cable may be attached to the bottom of the casing to relieve the tension on the upper casing couplings. During the lowering process, the casing grooves should be kept aligned to the final configuration desired so that later turning of the casing will be minimized. Extreme care must be taken at all times to prevent damage to or misalignment of the casing.

Experience shows that sand or pea gravel should not be used as backfill material unless it is absolutely necessary. These backfills tend to mask the movements, not allowing a rigid shear plane to reach the casing.

The grout usually consists of a cement-water mixture and is pumped through a small diameter plastic pipe attached to the outside of the casing during installation. The use of hydrated lime rather than cement is sometimes recommended to provide for a more responsive, somewhat weaker backfill. As previously discussed, grout may also be pumped through hollow drill rods and the bottom one-way valve until the annular space around the casing is completely filled. For very deep installations, grouting may be necessary at several levels. If grout is used with plastic casing, the heat of hydration of the grout or excess grout pressure can deform the plastic. This problem can be eliminated by maintaining the casing full of water until the grout has set or by grouting the hole in stages.

In many instances, the casing must be weighted with either drill rods or water to overcome bouyancy in water-or mud-filled holes. Adding water to the inside of the casing also helps protect against casing collapse. The orientation of the casing grooves may become misaligned during installation and grouting. If this occurs, and the casing can still be rotated, the casing should be given a final orientation adjustment so that one set of grooves faces the direction of anticipated movement. This may be accomplished by raising the casing slightly, turning it gently then lowering it back to its final elevation.

The top of the casing is normally capped to keep out debris. In most cases, a steel protective pipe installed around the top of the casing will discourage vandalism. The protective pipe is fitted with a lid, which may be locked in place.

Installing casing during construction should follow the same general procedures as those described in section 47. Typical inclinometer installations of each type are shown on figures 4-13 and 4-14.

e. ***Monitoring Procedure.***—The inclinometer installations are monitored at prescribed intervals. Inclinometer devices consists of a servo-accelerometer probe and a digital readout unit. The probes are designed to fit 1.9-, 2¾-, and 3⅜-inch o.d. casing. While setting up this instrument to take a set of readings, the guide wheels should be checked for bearing freeplay and tightened if necessary. A small amount of lubricant should be applied to each wheel bearing assembly. The cable connectors should be protected with caps to prevent damage or contamination to the connector contacts. An O-ring usually provides a water-tight seal between the cable and the probe; however, some probes are permanently connected to the cable. In that case, especially with lighter cables, the cable should be checked for damage near the connection.

The power to the readout unit is turned on and the system checked by holding the bottom of the probe stationary and moving the top along the measurement axis. The readout unit should display values with polarity corresponding to the given tilt angles. A calibration stand may be used if desired.

A pulley assembly is attached to the top of the casing. Usually, the probe must be installed in the casing before the pulley wheel can be fitted to the assembly. It is important that the wheels of the probe are properly seated in the premarked casing grooves before the pulley is installed. The probe is carefully lowered to the bottom of the casing, avoiding severe shocks to the instrument near the bottom. On the Slope Indicator type of pulley assembly, a jam cleat is located at the top of the pulley assembly. It is used to secure the cable and to provide a convenient depth index during the data collection process. The distance from the casing top to the jam cleat is 1 foot. The depth is controlled by pulling the cable through the cleat until the end of the foot mark has reached the rear of the jam cleat block. After the probe reaches the bottom of the casing, it is raised to the nearest foot mark, and the distance from the top of the casing to the probe is measured by means of the cable markings.

When the inclinometer casing is initially surveyed, it is important that the downhill groove be clearly marked and that the uppermost wheel be aligned with this mark for the initial set of readings. This is very important because the orientation of the readings is governed by the direction of this wheel. For every subsequent set of readings in this casing, the same wheel should be placed in the same groove used for the initial set of readings. Accurate records should be kept of the reference system used on a particular project.

Inclinometer measurements are generally recorded as readings in opposite grooves (180° apart) at each depth. The sum of the readings in opposite grooves at any given depth should be approximately constant for all measurements. Small differences between these sums indicate that opposite sides of the casing wall are not parallel. Comparing these sums in the field will eliminate large errors resulting from mistaken transcriptions, faulty equipment, or improper technique. When the sums are not nearly constant, the sensor, readout, and casing should be rechecked before continued use.

The data are written on the field data sheet and formated to facilitate quick conversion to computer coding. Because all inclinometer readings are referenced to an original set of measurements, extreme care must be taken to obtain an accurate and reliable initial set of observations. Measurements of the original casing profile should be established by a double set of data. If any set of readings deviates from the previous or anticipated pattern, the inclinometer should be checked and the readings repeated.

Careful attention must be given to depth measurements on the cable to realize the potential accuracy of the inclinometer system. The wheels of the inclinometer probe provide measuring points between which the inclination of the instrument is measured. To achieve optimum accuracy, the distance between each reading interval should equal the distance between the upper and lower wheels of the probe. Taking double or more data sets each time also improves the accuracy.

Despite precision manufacturing techniques used by most casing suppliers, the grooves in any section of casing may be slightly spiraled. During installation, the casing may become even more twisted so that at some depth, the casing grooves will not have the same orientation as at ground level. Because significant errors in the assumed direction of movement may result, casing for deep inclinometer installations should be selected

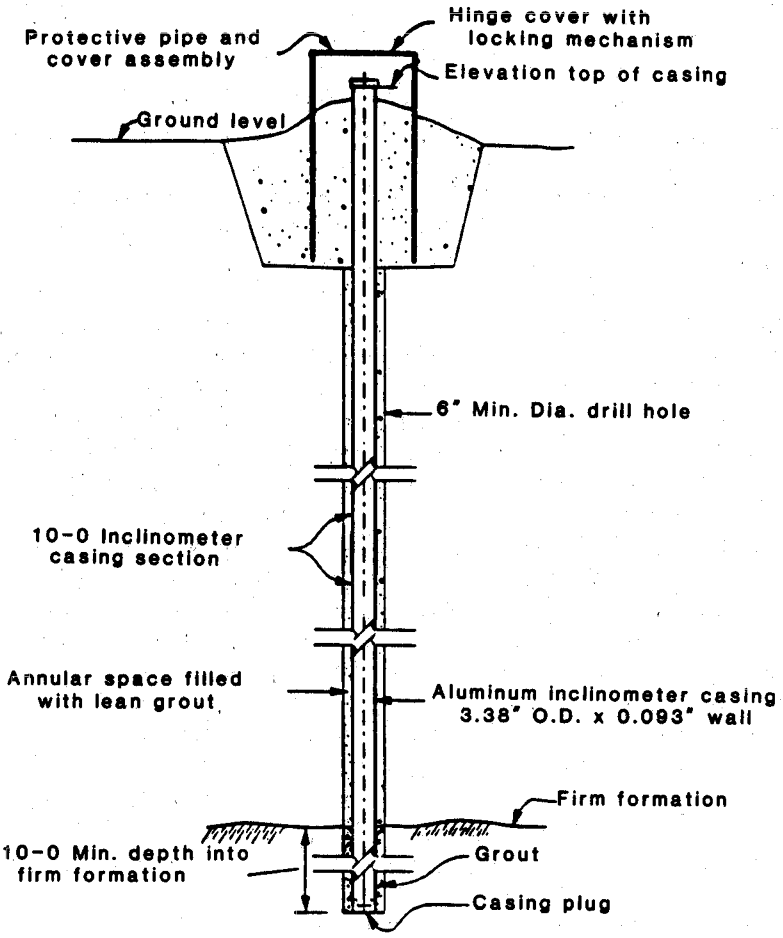


Figure 4-13.—Typical foundation and abutment inclinometer installation.

with great care and checked for spiraling before installation. Spiral measuring probes are available from the manufacturers, but they have had a somewhat unreliable performance record. Spiraling does not contribute to an error in magnitude of deformation, but it may prevent determination of the true direction of movement of the casing.

Automatic data recording and processing can reduce the time and labor involved in office computation of the data. Although the field recording is speeded up slightly, two experienced technicians can usually read and record at about the same speed as the automatic system. Automatic data recording contributes to the complexity of the measurement operation and can introduce an additional and significant source of error. With manual data recording, the technician can scan the data for errors in the check sums and make corrections or reread the casing on the spot. Most data recording systems do not allow this advantage; the data must be scanned for errors after being printed out in the office and before computer processing. However, one data recording system now allows a review of the data as it is being taken, so that corrections can be made as measurements are accumulated. This unit also allows field reduction of the data and comparison of the data with initial data files. Using the same observers and instruments for all measurements on a particular project is strongly recommended.

The measurement of settlement in an embankment installation is initiated by surveying to establish the top of the casing. A reference benchmark off the dam is used for consistency in data. Starting at the top, the settlement probe is lowered to each slip joint in the casing, and the depth to each point is read directly off the tape to the nearest 0.01 foot. As each section of casing is added during embankment construction, the above-mentioned settlement measurements are made.

All data except those recorded and transmitted automatically are entered on a field data form, as shown on figures 4-15 and 4-16.

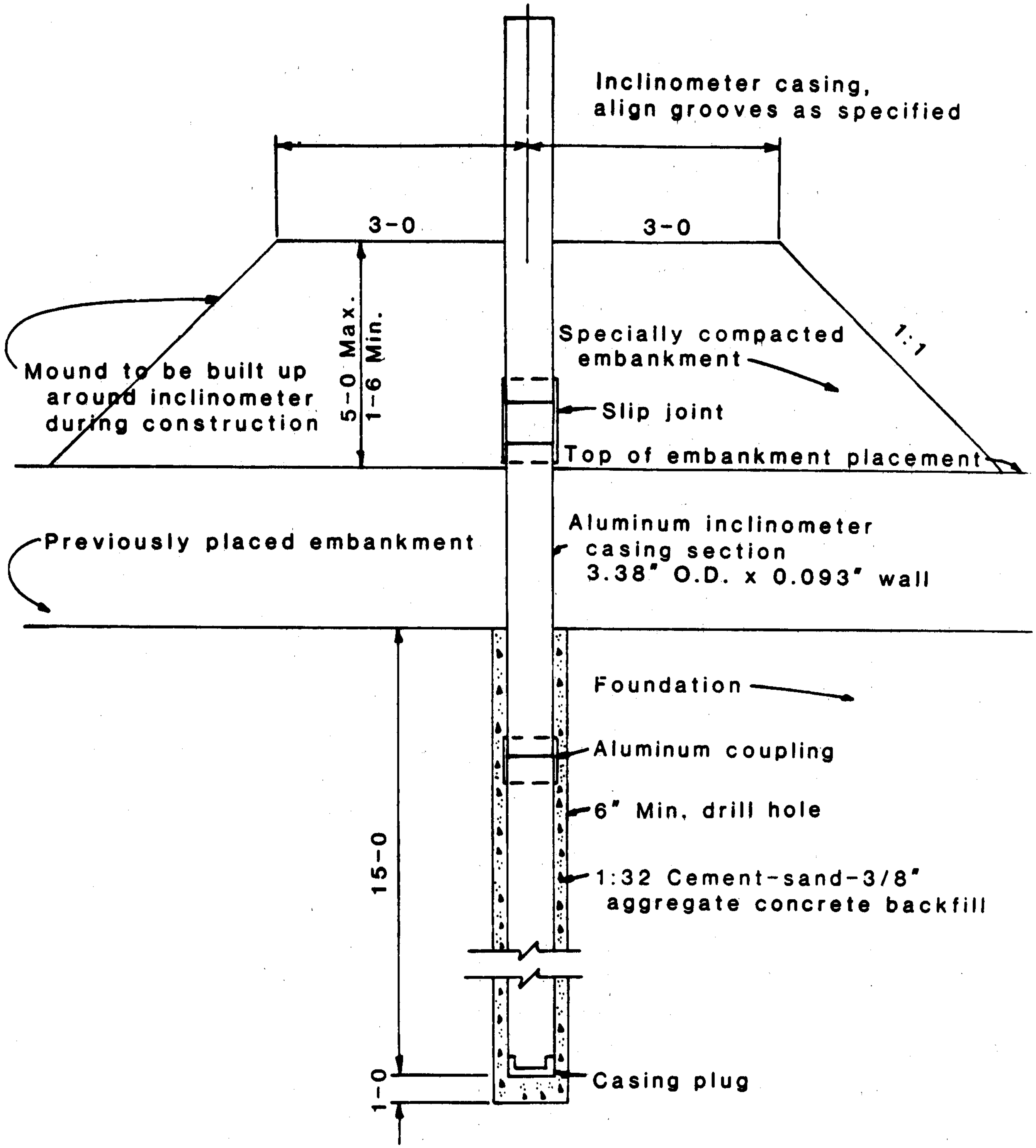
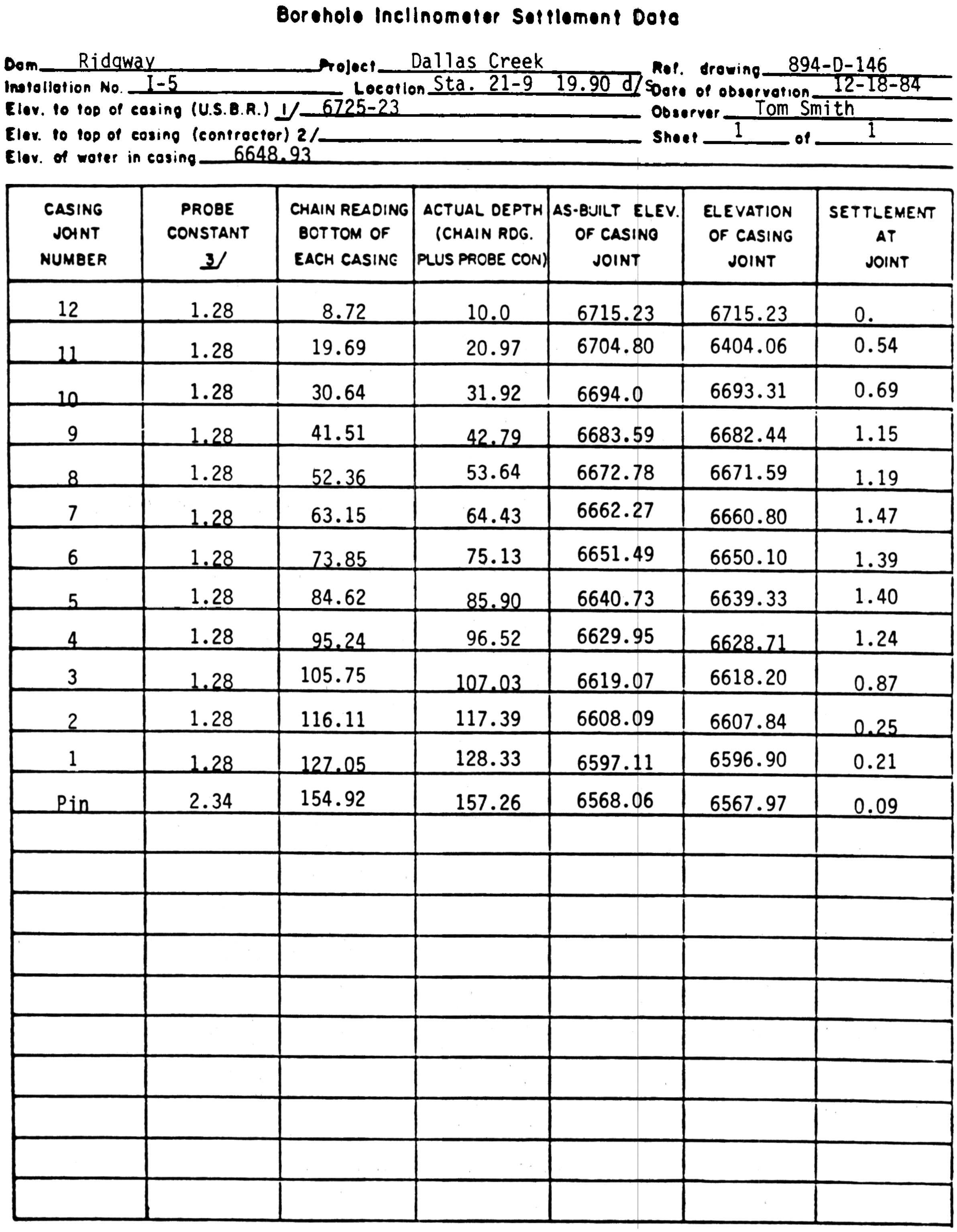


Figure 4-14.—Typical embankment inclinometer installation.



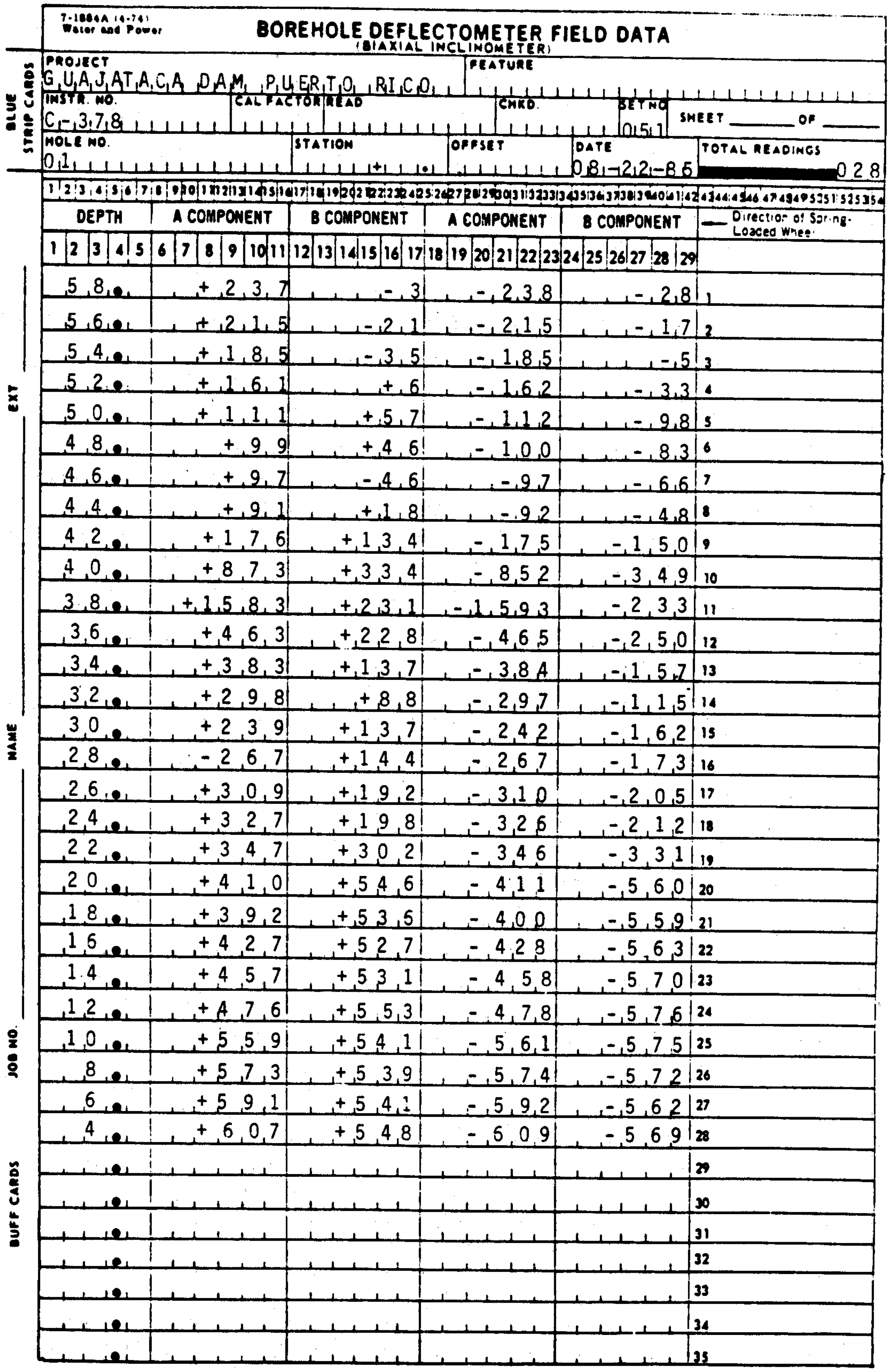
Borehole Inclinometer Settlement Data

Dam Ridgway Project Dallas Creek Ref. drawing 894-D-146
Installation No. I-5 Location Sta. 21-9 19.90 d/s Date of observation 12-18-84
Elev. to top of casing (U.S.B.R.) 1/ 6725-23 Observer Tom Smith
Elev. to top of casing (contractor) 2/ Sheet 1 of 1
Elev. of water in casing 6648.93

CASING JOINT NUMBER	PROBE CONSTANT 3/	CHAIN READING BOTTOM OF EACH CASING	ACTUAL DEPTH (CHAIN RDG. PLUS PROBE CON)	AS-BUILT ELEV. OF CASING JOINT	ELEVATION OF CASING JOINT	SETTLEMENT AT JOINT
12	1.28	8.72	10.0	6715.23	6715.23	0.
11	1.28	19.69	20.97	6704.80	6404.06	0.54
10	1.28	30.64	31.92	6694.0	6693.31	0.69
9	1.28	41.51	42.79	6683.59	6682.44	1.15
8	1.28	52.36	53.64	6672.78	6671.59	1.19
7	1.28	63.15	64.43	6662.27	6660.80	1.47
6	1.28	73.85	75.13	6651.49	6650.10	1.39
5	1.28	84.62	85.90	6640.73	6639.33	1.40
4	1.28	95.24	96.52	6629.95	6628.71	1.24
3	1.28	105.75	107.03	6619.07	6618.20	0.87
2	1.28	116.11	117.39	6608.09	6607.84	0.25
1	1.28	127.05	128.33	6597.11	6596.90	0.21
Pin	2.34	154.92	157.26	6568.06	6567.97	0.09

1/ Elevation at top of casing, computed. 2/ Elevation at top of casing surveyed by contractor. 3/ Distance from zero mark on chain to pawls on torpedo. The constant remains the same until the last reading when the torpedo is closed.

Figure 4-15.—Example form for borehole inclinometer settlement data.



7-1884A (4-74)
Water and Power

BOREHOLE DEFLECTOMETER FIELD DATA
(BIAXIAL INCLINOMETER)

BLUE STRIP CARDS

PROJECT: GUAJATACA DAM PUERTO RICO
FEATURE:
INSTR. NO.: C-378
CAL FACTOR:
READ:
CHKD.:
SET NO: 051
SHEET ____ OF ____
HOLE NO.: 01
STATION: + .
OFFSET: .
DATE: 08-22-85
TOTAL READINGS: 028

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54

DEPTH	A COMPONENT	B COMPONENT	A COMPONENT	B COMPONENT	— Direction of Spring-Loaded Wheel
1 2 3 4 5	6 7 8 9 10 11	12 13 14 15 16 17	18 19 20 21 22 23	24 25 26 27 28 29	
58 ●	+237	-3	-238	-28	1
56 ●	+215	-21	-215	-17	2
54 ●	+185	-35	-185	-5	3
52 ●	+161	+6	-162	-33	4
50 ●	+111	+57	-112	-98	5
48 ●	+99	+46	-100	-83	6
46 ●	+97	-46	-97	-66	7
44 ●	+91	+18	-92	-48	8
42 ●	+176	+134	-175	-150	9
40 ●	+873	+334	-852	-349	10
38 ●	+1583	+231	-1593	-233	11
36 ●	+463	+228	-465	-250	12
34 ●	+383	+137	-384	-157	13
32 ●	+298	+88	-297	-115	14
30 ●	+239	+137	-242	-162	15
28 ●	-267	+144	-267	-173	16
26 ●	+309	+192	-310	-205	17
24 ●	+327	+198	-326	-212	18
22 ●	+347	+302	-346	-331	19
20 ●	+410	+546	-411	-560	20
18 ●	+392	+536	-400	-559	21
16 ●	+427	+527	-428	-563	22
14 ●	+457	+531	-458	-570	23
12 ●	+476	+553	-478	-576	24
10 ●	+559	+541	-561	-575	25
8 ●	+573	+539	-574	-572	26
6 ●	+591	+541	-592	-562	27
4 ●	+607	+548	-609	-569	28
●					29
●					30
●					31
●					32
●					33
●					34
●					35

EXT

NAME

JOB NO.

BUFF CARDS

Figure 4-16.—Form 7-1884A, Borehole Deflectometer Field Data.

f. ***Maintenance.***—A regular maintenance program is essential to proper inclinometer monitoring. Repair or replacement of an inclinometer probe or readout unit because of misuse or improper maintenance can be expensive and can result in a shortage of data because of the downtime.

Upon completion of field work, the unit should be checked for superficial damage. Wheel fixtures and bearings should be checked for tightness, cleaned, and oiled. If worn, these parts should be replaced as soon as possible. Metal surfaces should be cleaned and protected with a coat of light oil. The cable should be inspected for damage to the outer coating material and to the depth markers. If depth markers are not vulcanized to the cable, they may move resulting in erroneous depth readings.

Cable connectors should remain capped when not in use and thoroughly cleaned after each use. Because most readout units are not completely weatherproof, they should be protected from moisture. The introduction of a few drops of water into the electronic circuitry can cause a galvanometer to read incorrectly or induce a drift on a digital voltage display. If readings are being made rapidly or if an automatic recorder is used, this drift may not be detected.

Equipment should be protected from shock and excessive vibration during transportation. Storage of this sensitive electronic equipment in a closed vehicle during the summer or in an unheated area in the winter should be avoided.

Periodic maintenance of the automatic data recorder, including the batteries, is required. Battery maintenance guidelines require the batteries to be completely discharged after several charge/discharge cycles. Nickel-cadmium batteries retain a form of memory capacity such that if they are repeatedly discharged to 10 percent of their capacity then recharged to full capacity, they may soon deliver only about 10 percent of their potential capacity. Complete discharge is defined as 5.0 volts. The minimum voltage of the internal batteries that will safely operate the unit should be carefully monitored because low voltage can result in lost data. The tape cassettes used with the recorder should be protected against dust, dirt, and temperature extremes, and should be cleaned periodically as prescribed by the instrument manufacturer.

Periodic maintenance should also be conducted on the cable reel if one is used. The rotating electrical contacts on the cable reel require periodic cleaning. Disassembly of the cable reel is required to service or replace these contacts. All systems components should be stored in a dry, moderate temperature environment when not in use.

g. ***Data Processing and Review.***—Data from the periodic monitoring are transmitted to the Structural Behavior Branch and processed as described in section 25. Data plots illustrating lateral movement and settlement are shown on figures 4-17 and 4-18, respectively.

52. Inclinometer (Fixed Position).—a. ***Usage.***—The fixed position, or in-place, inclinometer is a solid-state borehole inclinometer used to measure progressive changes in the angle of inclination at set locations within an inclinometer casing.

b. ***Advantages and Limitations.***—The fixed position inclinometer has the advantage over conventional inclinometers that it can be installed in locations that later become inaccessible to instrumentation personnel (for example, in the upstream face of a dam under the reservoir). The system can then be automatically read. The in-place inclinometer has two principal limitations: Only selected points along the profile of the hole are measured rather than the entire hole depth, and they are costly to purchase and install.

c. ***Description of Equipment.***—The system consists of six parts: in-place sensor, interconnecting electrical cable, the permanent inclinometer casing, remote terminal junction box, and readout equipment. The casing and the readout equipment have been described previously in section 51.

(1) *Sensor.*—The in-place sensor is very similar to the standard inclinometer probe described in section 51. An important exception is that the in-place sensor monitors only a given gauge length at a certain location in a hole. The sensor contains two servo-accelerometers mounted with the sensitive axes 90° apart to measure the angle of inclination of the longitudinal axes of the sensor in two orthogonal planes. The sensor is installed nearly vertically in the inclinometer casing and supported laterally in the casing by means of guide wheels. The sensor has a range of plus or minus 30° with a resolution of 0.001 inch for a 10-foot gauge length. The gauge length is the vertical distance between the universal joints at the centerline of the guide wheels of the sensor and the end of the gauge length tubing. The sensor is suspended from the top of the casing by permanent support rods (tubes).

(2) *Electrical Cable.*—The sensor has an electrical cable terminating at the junction box at the top of the casing or at another location. This cable has six stranded copper conductors, No. 20 AWG, a single braided shield overall, and a black polyethylene jacket.

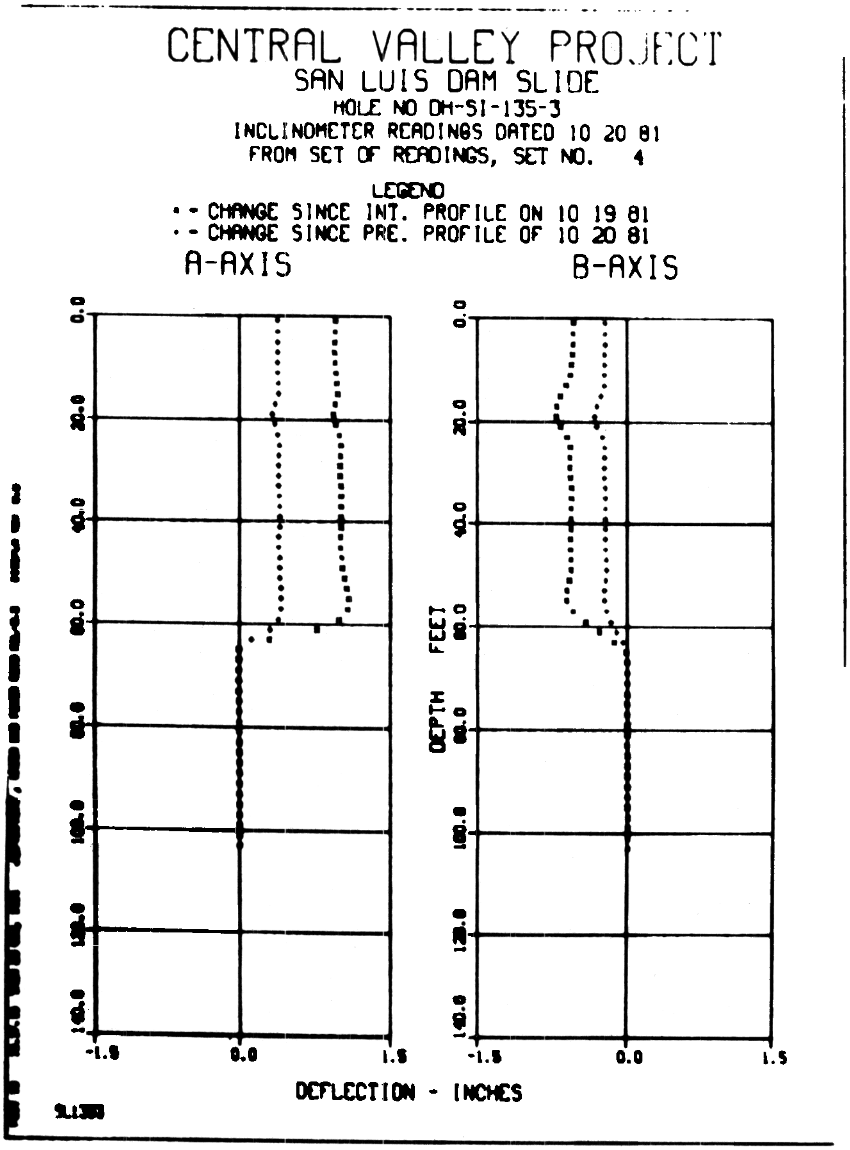


Figure 4-17.—Example plot of lateral movement data measured by inclinometer.

(3) *Junction Remote Terminal Box.*—The junction box is intended for manual readout of the sensors; it is able to read up to 16 sensors installed in the hole. The junction box can be installed at the top of or far from the hole. A multi-pin conductor is provided on the outside of the box for quick connection to the readout equipment. Some fixed inclinometers have been fitted with alarm systems to warn of excessive movement. If alarms are installed on the sensors, an excitation and alarm unit is attached to the cables from the junction box. Up to 30 sensors can be used to trigger a single alarm unit.

d. ***Installation.***—Before installation, the inclinometer casing should be surveyed as described in section 51. This data should be reviewed with respect to verticality of the hole so that full-scale limits are not likely to be exceeded by the sensor. Moreover, sharp bends at or above the depth of sensor installation that would prevent installation should be checked. The casing should be permanently marked on the groove that is used to determine the A+ axis of the casing. The fixed wheel of the sensor should be placed in this A+ groove during installation.

The support tubing and sensors are arranged in order of installation, and the sensors connected to their gauge length tubes. All sensors are then to be tested for proper A and B axis polarity and stability.

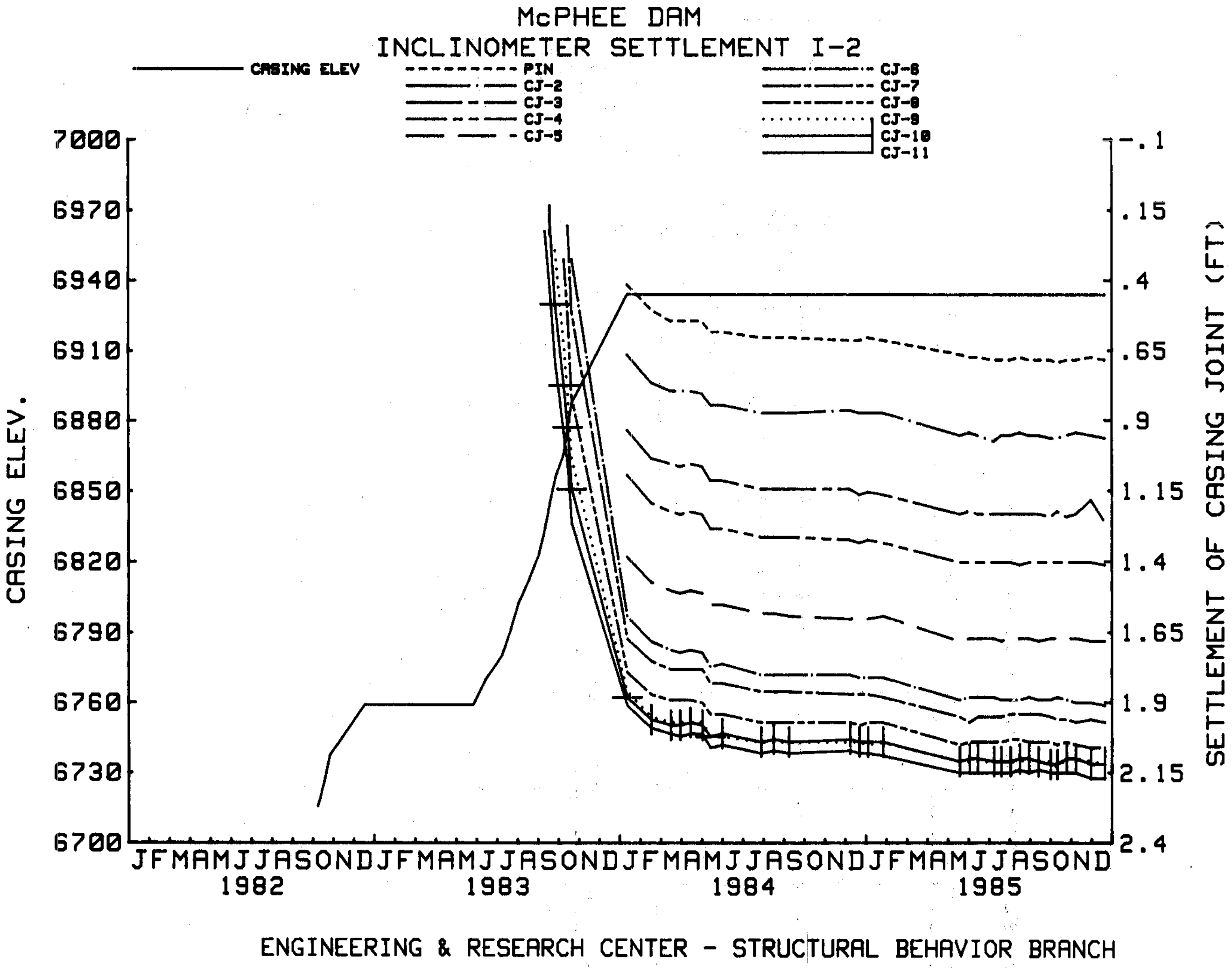


Figure 4-18.—Example plot of settlement data measured by inclinometer.

The sensors are installed by lowering them and the tubing into the casing and aligning the A+ polarity of the sensor to the A+ groove on the casing. The sensor and connection tubing are lowered by use of a steel retrieval cable attached to the bottom sensor. This cable must be attached to the rods during installation to avoid tangling with electrical cables. As the second set of wheels of the sensor are placed in the casing, a special alignment jig is used because of the universal joint on these wheel. Once the sensors and rods are all in place, the rods are attached to the casing by a special cross that fits inside the casing. The sensor should then be checked for operation. The sensor can be removed by the retrieval cable if a complete profile of the hole is required by using a moveable inclinometer probe.

e. ***Monitoring Procedure.***—In-place inclinometers are read at a central location. Sensors from many locations or many depths can be read at a central location. The cost of the cable dictates that the reading location be placed as closely as possible to the sensors. The sensors are read by connecting the readout device to the junction box, then completing the following steps:

(1) Turn the power switch ON and allow readout 10 minutes for warmup.

(2) Turn the power switch to BATTERY TEST; the digital display should indicate 6.0 volts for a fully charged battery. Do not operate the readout if the voltage is below 5.5 volts.

(3) Set the junction box selector switch to SENSOR NO. 1, allowing at least 1 minute for the sensor to stabilize.

(4) Record the magnitude and polarity of the reading displayed. Both the A and B components should be recorded. Some readout devices require switching from the A component to the B component.

(5) Set the junction box selector switch to the next sensor and repeat steps 3 and 4. Whenever the selector switch is set to a new sensor, 1 minute should be allowed for the sensor to stabilize.

f. ***Maintenance.***—The periodic maintenance required for the in-place inclinometers can be accomplished by properly maintaining the readout device (described in section 51) and the junction box. To ensure good electrical contact, periodically wipe the contacts with a clean dauber or a cloth dipped in alcohol. Before disconnecting the cable from the junction box after the readings, carefully wipe the connector to remove any water or dirt. When disconnected, always keep the protective cap over the contacts.

g. ***Data Processing and Review.***—The data read are in a form that usually can be used to check for any movement when the measurements are taken. Because the purpose of the in-place inclinometer is to monitor changes in the deflection of the inclinometer casing, the data must be summarized on data sheets to compare successive surveys. The field data can be tabulated on the data sheet showing the date of the reading and the reading. The data do not usually need to be converted to angles to be reviewed. The periodic change in deflection is determined as follows: Change = new reading - initial reading. The initial reading is used as a baseline reference for all future readings. If the inclination is required, the tilt angle, Θ, for any single reading at any depth may be determined as follows:

$$\text{Instrument Reading} = 12L \text{ Sine } \Theta,$$

$$\Theta, \text{(degrees)} = \text{(Arc Sine)} \frac{\text{Instrument Reading}}{12L}$$

where:

L = gauge length, in feet.

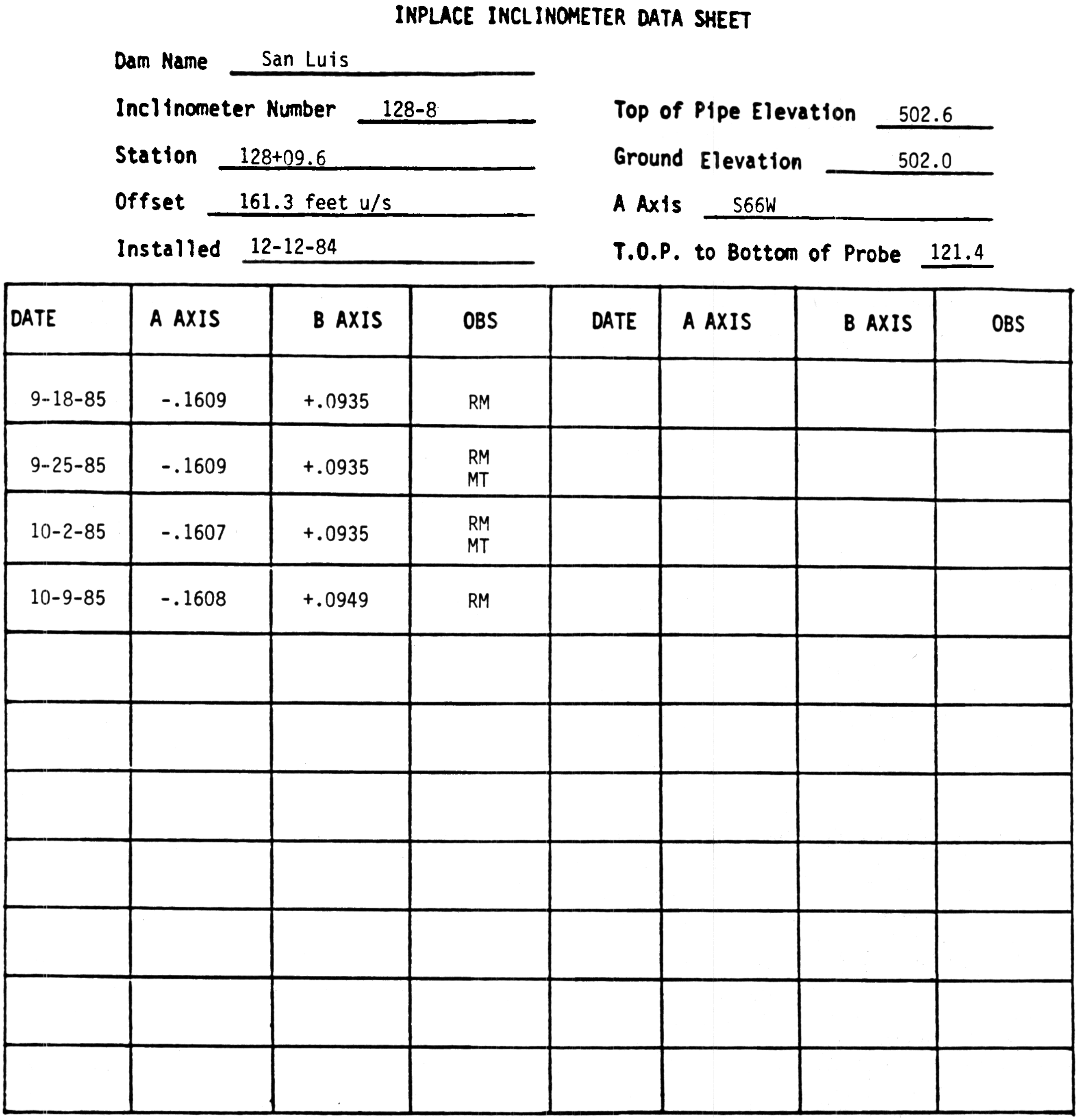
Figure 4-19 shows an example field data sheet.

The data are transmitted to the Structural Behavior Branch for analysis. Upon arrival, the data are processed, reviewed, and reported as discussed in section 25. An example plot of the data measured by in-place inclinometer is shown on figure 4-20.

53. Extensometers.—a. ***Usage.***—Multiple position (multipoint) extensometers are designed to measure axial displacement of fixed points along their length. Extensometers are normally installed in uncased boreholes, but may be placed in an embankment during construction. The devices are suitable for installation vertically, horizontally, or an any angle. Extensometers used by the USBR include the rod-type, wire-type, and the tape extensometer.

b. ***Description of Equipment.***—The rod-type extensometer consists of multiple anchors installed at different depths in a drill hole or at different locations in an embankment. Aluminum rods inside hollow tubes extend from each anchor to a reference head at the collar of the hole. All measurements of movements are made at the reference head. As an anchor moves, the resulting movement of the rod attached to that anchor is measured relative to the reference head. Depending on the size of the drill hole, theoretically as many rods and anchors may be installed as desired, but normally only 5 to 10 anchors are installed in each hole. Anchor movements may be measured either mechanically (e.g., by depth gauges) or electrically (e.g., by linear potentiometers). Various types of anchors are available, but most operate by using radial expansion to lock the anchor in place. Figure 4-21 shows a rod-type extensometer. The device can measure up to 4 inches of movement before requiring resetting. Specification EDI-26 (app. A) describe the extensometers.

Wire-type extensometers have tension wires instead of rods extending from the anchors to the reference head. Normally six or eight anchors are connected to each reference head. The sensor head end of the wire connections contains a stainless steel cantilever device for each wire. Changes in distance between the anchors and the head are sensed by deflections in the cantilevers. Movements of the cantilevers are detected through the use of strain gauges, dial gauges, or vibrating-wire transducers. Figure 4-22 illustrates this device. A high degree of accuracy is available with this device, but only 0.60 inch of movement is allowed before resetting of the gauge and wires is required. Some USBR experiences have indicated concern about the long-term reliability and performance of wire extensometers, particularly cantilever extensometer devices.



INPLACE INCLINOMETER DATA SHEET

Dam Name San Luis

Inclinometer Number 128-8

Station 128+09.6

Offset 161.3 feet u/s

Installed 12-12-84

Top of Pipe Elevation 502.6

Ground Elevation 502.0

A Axis S66W

T.O.P. to Bottom of Probe 121.4

DATE	A AXIS	B AXIS	OBS	DATE	A AXIS	B AXIS	OBS
9-18-85	-.1609	+.0935	RM				
9-25-85	-.1609	+.0935	RM MT				
10-2-85	-.1607	+.0935	RM MT				
10-9-85	-.1608	+.0949	RM				

Figure 4-19.—Example inplace inclinometer field data sheet.

Tape extensometers are very accurate for measuring the relative movement of two exposed points. The device consists of a dial gauge and a tape, which is merely stretched to a constant tension between two points in any direction. Figure 4-23 shows this device. Lengths of up to 100 feet are available with accuracies to the nearest 0.005 inch.

c. ***Installation.***—Upon completion and cleaning of the borehole, the deepest anchor is inserted in its desired position and fixed in place. A connecting rod and tube or a wire previously attached to the anchor should extend to the reference head. Other anchors are inserted, progressing outward toward the reference head. After all anchors are in place and test readings taken, the hole is grouted full using a thin sand-cement grout. If bore wires are used, the hole is not grouted.

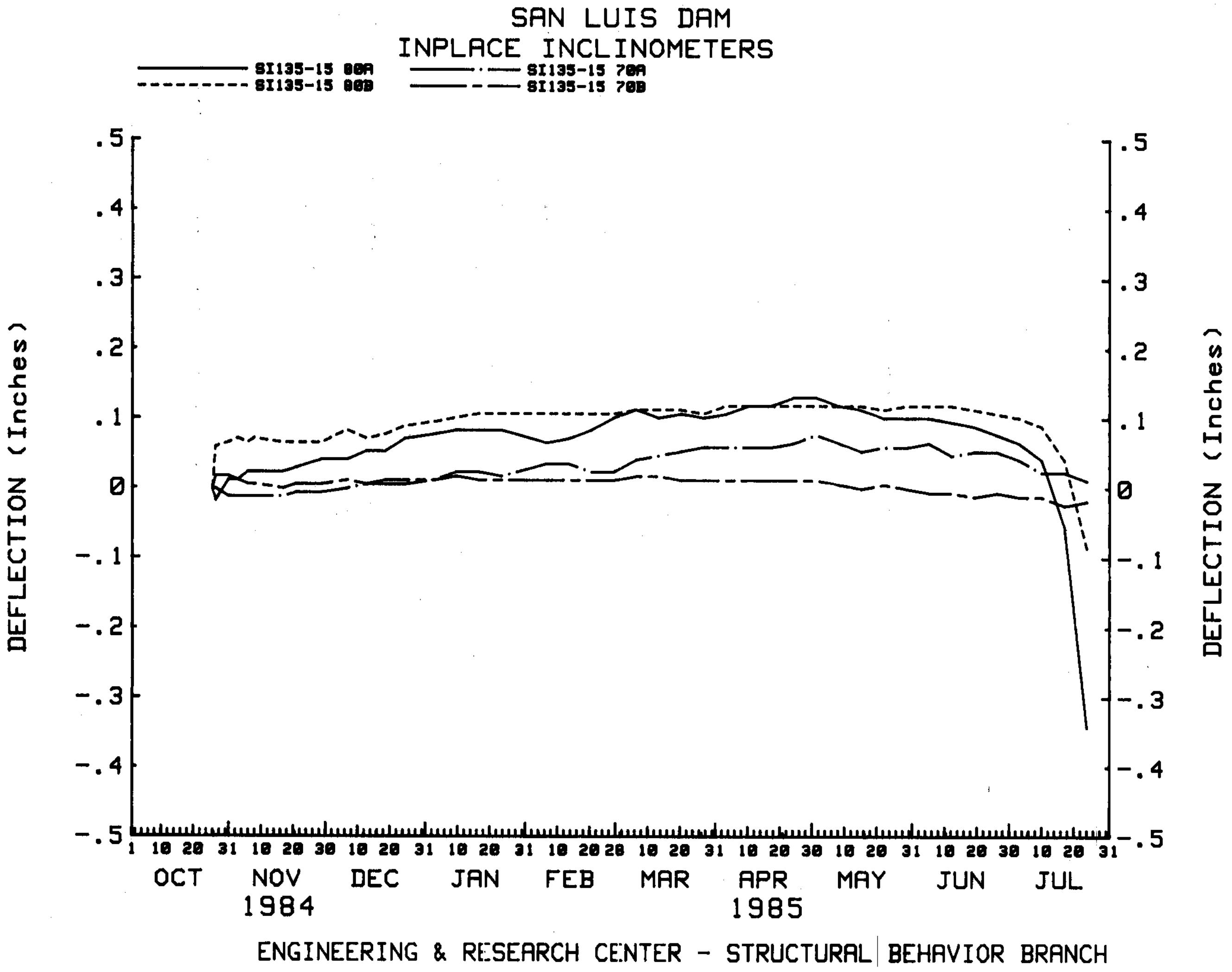


Figure 4-20.—Example plot of deflection data measured by inplace inclinometer.

d. ***Monitoring Procedure.***—Extensometers are read periodically on a prescribed schedule basis. The readings may be taken either mechanically (e.g., using dial [depth] gauges) or electrically (e.g., using portable readout devices).

e. ***Maintenance.***—The reference head must be kept free of dust, grit, and moisture to ensure proper, long-term operation. Occasionally, when sufficient movement has occurred, the reference head must be reset. This operation must be conducted precisely according to the manufacturer's instructions. When the devices are reset, an additional constant must be added to or subtracted from future readings to determine the total movement since installation.

f. ***Data Processing and Review.***—Data from extensometer observations are entered on a field data form as shown on figure 4-24 and transmitted to the Structural Behavior Branch. Data processing and review are then conducted as outlined in section 25, and plots of extensometer data prepared as shown on figure 4-25.

54. Shear Strips.—a. *Usage.*—Shear strips are used to detect failures or differential movements in rock, soil, or concrete materials. They consist of an electrical circuit attached to a brittle strip of material. The strip may be hundreds of feet in length, it may be grouted into a borehole, or it may be attached to a rock or concrete surface.

Differential movement along the shear strip causes tension or shear failure of the strip, breaking the electrical circuit. Resistors placed at regular intervals along the strip enable the failure location to be determined. Shear strips that require different amounts of shear or strain to create failure are available.

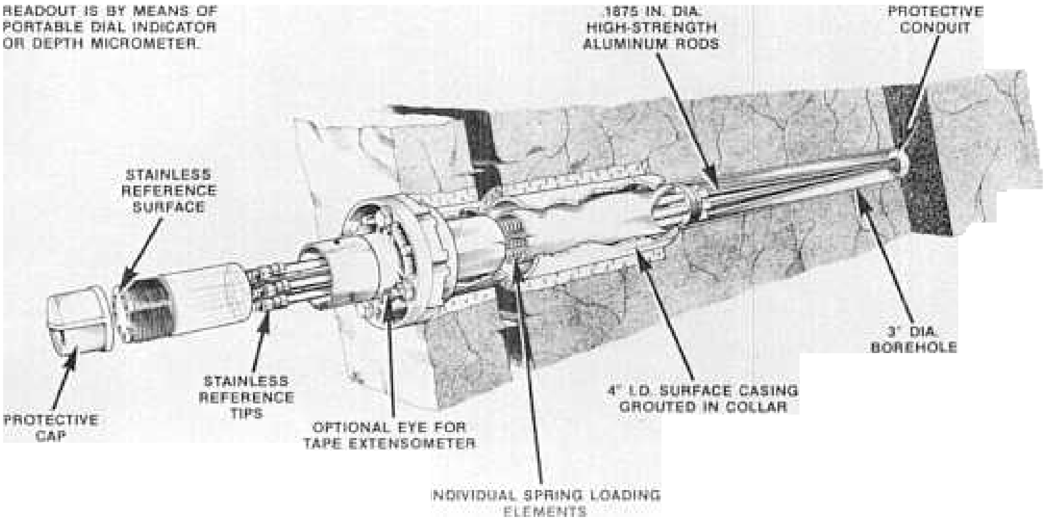


Figure 4-21.—Typical rod-type borehole extensometer. P801-D-81019.

b. ***Advantages and Limitations.***—In most applications, a shear strip is intended as a warning device. It serves as a quick indicator of the integrity of a structure because it can rapidly show whether movements have occurred. If desired, a shear strip can be wired to give immediate warning in the form of flashing lights or alarms.

A limitation of shear strips is that although they show that a failure has occurred and the location of the failure, they do not indicate the amount or rate of movement. If such data are necessary, borehole extensometers or inclinometers should be used instead.

c. ***Description of Equipment.***—Figure 4-26 illustrates a typical shear strip device. Its components consist of a shear strip with electrical cable, shear strip readout unit, and terminal readout box.

(1) *Shear Strip and Cable.*—A shear strip consists of two copper conductors bonded to the surface of a brittle phenolic backing. The two conductors form two parallel paths that are connected by as many as 100 equally spaced resistors. The entire assembly is completely waterproofed.

Electrical cables (2-wire) should be attached to each end of the shear strip. The cable running from the far end is normally placed in a conduit so it may move freely when the installation is subjected to differential axial or lateral movement. Specification EDI-27 (app. A) covers the strip, accompanying wiring, readout units, and terminal box.

(2) *Readout Unit.*—The shear strip readout unit must be capable of applying a voltage across the shear strip resistors. This unit is basically composed of a null balance galvanometer and a 3-digit binary current switch. The unit contains a counter that directly indicates the number of resistors between the unit and a break in the strip.

(3) *Terminal Readout Box.*—The electrical leads from the shear strip should terminate at a small (6- by 6- by 4-inch) readout box located at a readily accessible point.

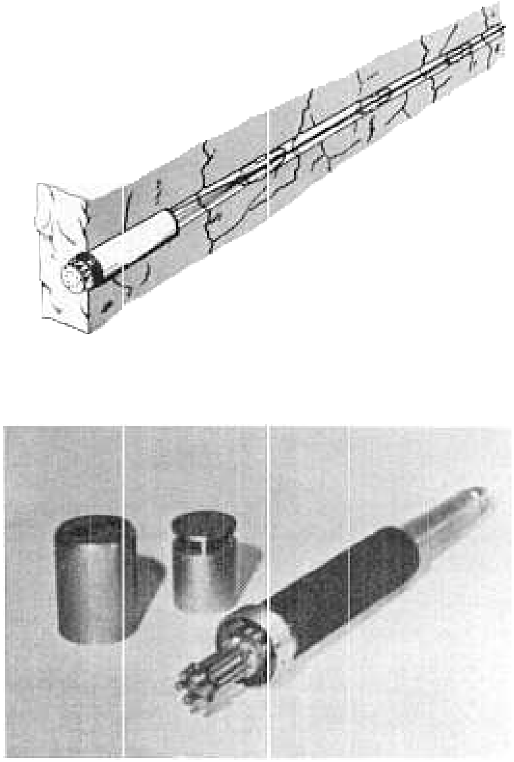


Figure 4-22.—Typical wire-type borehole extensometer. P801-D-81020.

d. ***Installation.***—Shear strips are installed in boreholes only after the hole is completed and cleaned. Any conventional size drill hole can be used for shear strip installation; however, the holes are usually 3 inches in diameter. A zip cord signal wire is normally connected to the shear strip at the factory, where the standard length is sufficient to extend 10 feet beyond the near end of the shear strip. If signal wires are to be connected in the field, they should be provided with a distressing loop. The wire connection is waterproofed by wrapping aquaseal around the joint and covering the aquaseal with Scotch 88 vinyl tape.

The signal wires should be plugged into the DBS-2 readout box, and the reading on the readout box should agree with the known total of resistors in the shear strip. The same number should be read on both the NEAR and FAR switch positions. With the shear strip in a loop, flex it gently one way then the other and observe the DBS-2 reading; it should not change. If the reading does change, there is a bad or broken connection that needs repair. Splicing instructions are given in the appendix of the manufacturer's manual. The entire shear strip could be immersed in water to check the waterproofing. Again, the DBS-2 reading should not change. If it does, then the waterproofing must be inspected and repairs made as necessary. If the strip passes these preliminry tests, it can be concluded that it was not damaged in shipment and is ready to be installed.

Installation of the shear strip in a drill hole is accomplished by attaching a small weight to the far end of the strip then lowering the strip, with electrical cable, into the hole. With the strip taut and extending the entire length of the drill hole, the bottom 3 feet of the shear strip should be grouted into place, using a backfill grout mixture of a 1:1 water-cement neat grout. This grout should be allowed to set for 24 hours. The electrical cable from the far resistor should be inserted in a 1-inch-diameter schedule 40 PVC pipe, lowered into the hole, and placed on top of the grout mixture. The pipe should remain in the hole and around the cable during grouting. The shear strip should be pulled taut and the remainder of the hole grouted with the backfill grout mixture from the bottom of the hole up.

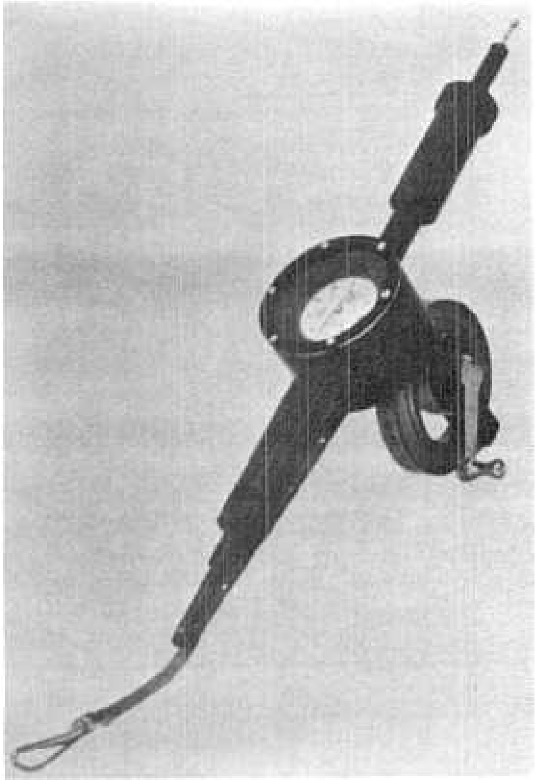


Figure 4-23.—Typical tape extensometer. P801-D-81021.

e. ***Monitoring Procedure.***—To monitor the device one set of electrical leads must be attached to the readout device, usually starting with the near leads. The readout counter is then turned on and read. If the number of resistors counted equals the total number on the shear strip, then no failure has occurred. However, if the number of resistors counted is less than the total number on the strip, then a failure has occurred just beyond the number of resistors counted. The readout device is then attached to the far leads, and the number of resistors is again counted. If the number of resistors counted using far leads plus the number counted using the near leads equals the total number on the entire strip, then the failure locations has been determined within the accuracy of the spacing of the resistors. If the number of resistors counted from each set of leads is less than the total number in the strip, then more than one failure has occurred, and the approximate location of at least two of the failures has been determined. Reading are entered on the field data form shown on figure 4-27.

f. ***Maintenance.***—Normal periodic cleaning and protection from moisture and corrosion is required for the terminal box and the readout unit. No maintenance of the shear strip is possible. Battery replacement for the readout unit is required periodically.

g. ***Data Processing and Review.***—Field data are transmitted to the Structural Behavior Branch for processing and review as described in section 25.

55. **Radiosonde Systems.—a.** ***Usage.***—The radiosonde system was developed by the Idel Company to provide a means of measuring deflections (vertical, horizontal, or at any angle) in a dam. The USBR uses it primarily to obtain horizontal deflection determinations. Vertical movements of horizontal tubes are determined using a water level device inside the tube. Only New Melones Dam[2] now has radiosonde equipment installed (see fig. 4-28). This dam was designed and constructed by the U.S. Army Corp of Engineers.

b. ***Advantages and Limitations.***—The radiosonde and watersonde devices yield a horizontal or vertical profile along the tube. Limitations to their use include difficult installation and relatively expensive installation

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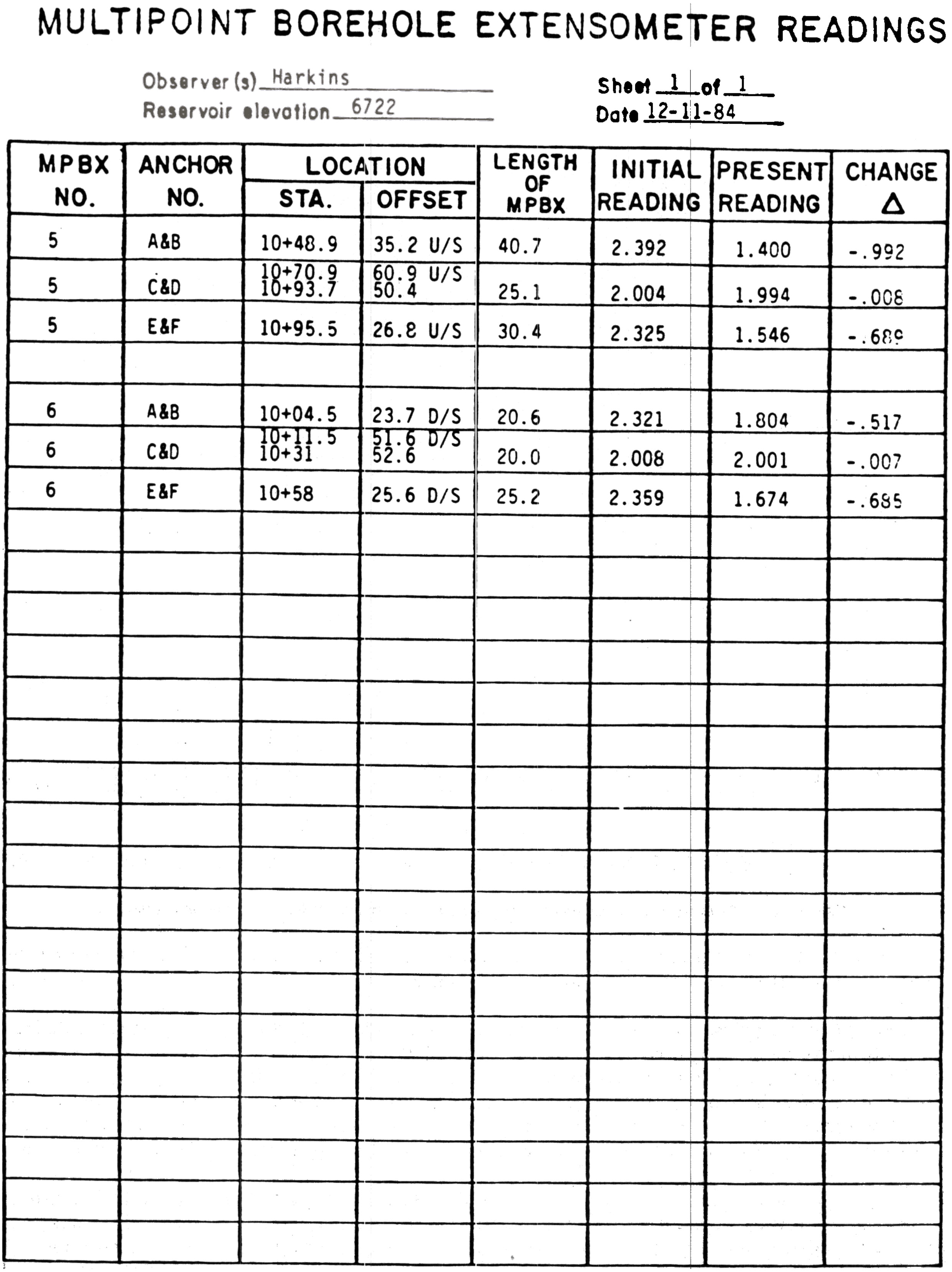
[2] New Melones Dam is a rockfill dam, 625 feet high and 1,560 feet long, located on the Stanislaus River in California.



MULTIPOINT BOREHOLE EXTENSOMETER READINGS

Observer(s) Harkins
Reservoir elevation 6722

Sheet 1 of 1
Date 12-11-84

MPBX NO.	ANCHOR NO.	LOCATION		LENGTH OF MPBX	INITIAL READING	PRESENT READING	CHANGE Δ
		STA.	OFFSET				
5	A&B	10+48.9	35.2 U/S	40.7	2.392	1.400	-.992
5	C&D	10+70.9 10+93.7	60.9 U/S 50.4	25.1	2.004	1.994	-.008
5	E&F	10+95.5	26.8 U/S	30.4	2.325	1.546	-.689
6	A&B	10+04.5	23.7 D/S	20.6	2.321	1.804	-.517
6	C&D	10+11.5 10+31	51.6 D/S 52.6	20.0	2.008	2.001	-.007
6	E&F	10+58	25.6 D/S	25.2	2.359	1.674	-.685

Figure 4-24.—Example data sheet for multipoint borehole extensometer readings.

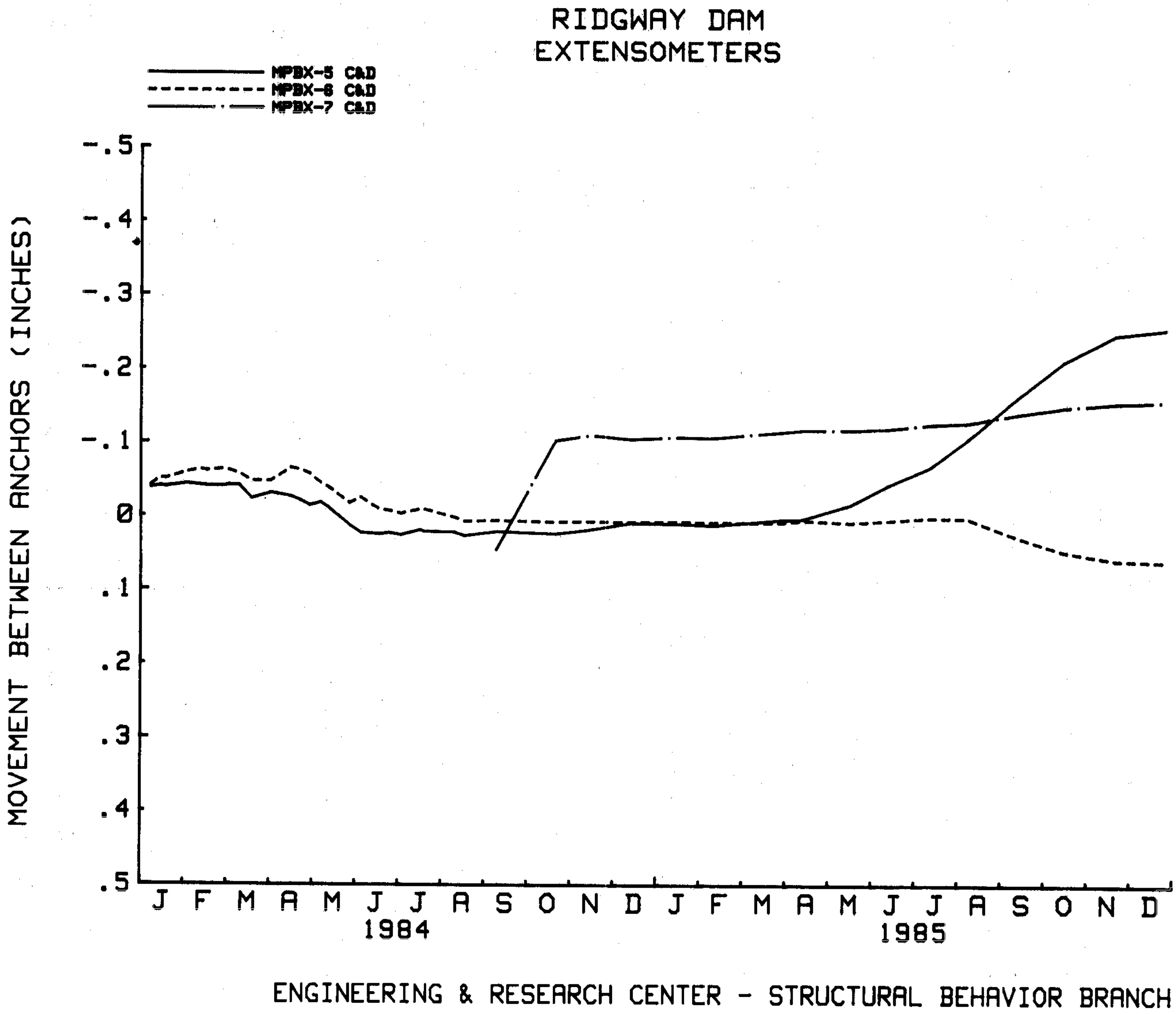


Figure 4-25.—Example plot of movement data measured by multipoint borehole extensometer.

and maintenance. The devices are rather time consuming to read, and some questions concerning their accuracy have arisen. However, it should be stressed that USBR opinions are based solely on the single present installation.

c. ***Description of Equipment.***—The device consists of 3-inch-o.d. PVC tubing of any length installed in an essentially horizontal (usually there is a slight slope to facilitate drainage) configuration. At regular intervals of 5 to 30 feet, larger diameter steel or aluminum rings (usually 12 to 24 inches in diameter) are installed around the PVC tube. Slip joint couplings of larger diameter tubing sealed with O-rings are used to allow horizontal movements. The far end of the tube is anchored with concrete, as shown in figure 4-29. A radio transmitter device is pulled by a cable through the tube, and radio signals indicate the location of each metal ring.

The instrument house contains an electric winch, reading scales, and a manometer gauge to facilitate use of an elevation measuring device known as a full settlement profile gauge, or watersonde. The watersonde device, which consists of a probe with an internal manometer connected to the control house manometer by two small (¼-inch) plastic tubes, is pulled through the PVC tube, stopping at predetermined locations to take readings.

d. ***Installation.***—The horizontal tubes and metal rings are installed during construction of the dam. A 2-foot-deep trench is dug at the desired location. In this trench the tubing is assembled with the slip joints,

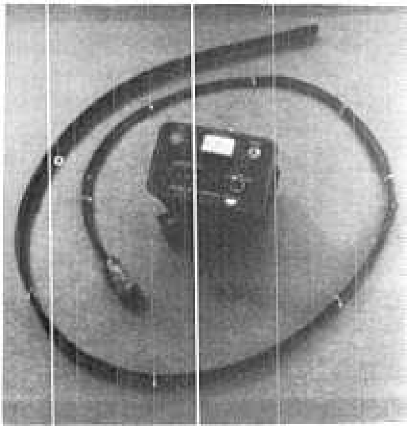


Figure 4-26.—Typical shear strip. P801-D-81022.

SHEAR STRIP DATA

Dam Davis Creek
Reservoir elevation 4500.00
Tailwater elevation 4300.00

Observer(s) Goins
Date 5-1-86
Sheet 1 of 1

Shear strip number	Initial near resistor number	Current near resistor number	Initial far resistor number	Current far resistor number
SS-1	100	100	100	100
SS-2	98	97	98	01
SS-3	50	45	50	03

Figure 4-27.—Example shear strip field data sheet.

Figure 4-28.—Typical radiosonde installation. P801-D-81023.

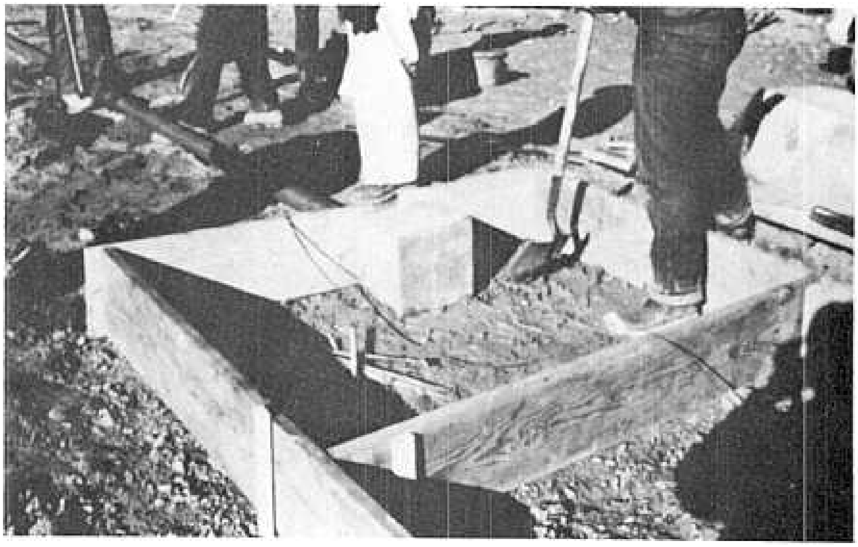


Figure 4-29.—Far end of radiosonde installation. P801-D-81024.

and the concrete anchor block with cable pulley and cable is threaded in place. The metal rings are installed at predetermined locations. Care must be taken that the metal rings encircle and are exactly perpendicular to the PVC tubing. Select backfill material is hand-tamped to an elevation 2 to 4 feet above the tubing. Backfill materials and methods are similar to those described for tubing bundles in section 29. Monitoring should begin immediately after installation but before backfilling.

e. ***Monitoring Procedure.***—The cover of the radiosonde PVC tube should be removed and the radio transmitter device attached to the cable in the tube. The radio transmitter is slowly pulled into the tube until a radio signal is received, indicating that a metal ring has been detected. At that point, a reading of distance from the end of the tube is made directly off the attached tape, and this reading is referenced to a table in the instrument house. Readings continue to the end of the tube. These readings may be checked as the transmitter is retracted.

The radio transmitter device is removed from the tube and the watersonde probe is attached to the pull cable. The attached plastic tubes are then filled with water and connected to the control house manometer. The water probe is pulled through the tube stopping to take readings at predetermined distances. Readings of water elevation are made directly from the instrument house manometer and recorded on the field data form, as shown on figure 4-30.

f. ***Data Processing and Review.***-The field data are transmitted to the Structural Behavior Branch for processing and review as described in section 25. Plots of horizontal and vertical deflections are then generated for review.

RADIOSONDE READINGS

Modified 8-20-85 for

Dam New Melones

Project Central Valley

Ref. Dwg.

Sheet 1 of 1

Add to Dist. 4.75 ft.

Date of Observtion 10-2-84

Observer EA

Fill ELEV. 1136.0

Cable Correction 1.000602

Cable Mark			A_1		A_2		B_1		B_2		Reference		Present Distance			
	0	00	0	00	0	00	0	00	0	00	5	39	4	75		64
	20	00	1	55	1	70	1	98	2	09	23	56	22	93		63
P	30	00	1	71	1	85	1	09	1	21	33	46	33	30		16
	40	00	1	59	1	74	1	99	2	13	43	51	42	91		60
	60	00	1	67	1	79	2	01	2	13	63	51	62	89		62
P	70	00	1	75	1	86	2	16	2	28	73	41	72	78		66
	80	00	1	64	1	78	2	10	2	23	83	51	82	86		65
	100	00	1	64	1	80	2	10	2	23	103	48	102	87		61
P	110	00	1	86	1	99	2	26	2	37	113	37	112	70		67
	120	00	1	67	1	79	2	18	2	30	123	45	122	84		61
	140	00	1	74	1	87	2	21	2	34	143	43	142	79		64
P	150	00	1	79	1	93	2	26	2	38	153	40	152	75		65
	160	00	1	71	1	86	2	21	2	34	163	48	162	82		66
	180	00	1	71	1	85	2	16	2	27	183	45	182	86		59
P	190	00	1	80	1	95	2	29	2	41	193	37	192	75		62

Figure 4-30.—Example data sheet for radiosonde water level readings.

Chapter V

SURFACE MOVEMENT MEASURING DEVICES

56. General Considerations.—Surface movement devices commonly consist of monuments installed on the surface of embankment dams or abutments, measurement points installed in concrete structures on or near the dam, tiltmeter devices installed on concrete or other appurtenant structures, or crack measuring devices installed in concrete or piping structures. The devices are used to measure total horizontal, vertical, rotational, or differential crack movements in any plane desired at a dam. The majority of these devices are commonly read using surveying techniques referenced to nonmoving monuments located off the dam.

57. Tiltmeters.—**a.** ***Usage.***—Tiltmeters are portable, rapid, and easy-to-read devices used to monitor the horizontal or vertical tilt (i.e., rotational movement) of structures and rock masses. They are generally affixed to the surface of such structures so that the tiltmeter plate moves with the structure. Tiltmeters have thus far been used only at one dam, but they were also used for monitoring slide movements at another site.

b. ***Advantages and Limitations.***—Tiltmeters are lightweight, compact, and are a relatively inexpensive method of obtaining rotational movement data. The data are, however, limited solely to the movement of the structure or rock mass to which they are affixed. The rate of movement can only be determined by comparing successive readings. A recently developed tilting system, which has not yet been used by the USBR, could make tiltmeters systems more desirable. The new system uses an electrolytic gravity sensor that, combined with modern, reliable electronics, provides continuous data about the angular motions of a structure.

c. ***Description of Equipment.***—Figure 5-1 illustrates the device and its functioning parts. The three basic parts of a tiltmeter device are the mounting tilt plates, the sensor device, and the readout indicator. Specification EDI–28 (app. A) covers these components.

(1) *Mounting Tilt Plates.*—A mounting plate, cast from specially formulated porcelain, containing four sensor orientation pegs in the upper surface is affixed to the rock, concrete, or metal surface to be measured. The plates are bonded to the surface using a grout or epoxy resin, with a set of orientation pegs aligned in the direction to be measured. The plates are typically 6 inches in diameter and ¾ inch thick with the four pegs spaced 4 inches apart across the center of the plate. A ceramic material is used to ensure maximum temperature stability.

(2) *Tiltmeter Sensor.*—The portable tiltmeter sensor utilizes two closed-loop, force-balanced, servo-accelerometers specifically designed for tilt measurements. The accelerometers are set at 90° angles to each other. The sensor body consists of a steel plate base and an aluminum housing around the accelerometer.

(3) *Readout Indicator.*—A readout indicator is used to indicate the angle of inclination of the tiltmeter sensor. Typically, the indicator can read over a standard operating range of plus or minus 30° from vertical or horizontal. The unit is powered by an internal rechargeable battery.

d. ***Installation.***—The mounting plates are installed using either a grout or an epoxy resin to firmly affix the plate to the side or top of the structure or rock surface to be measured. Installation can also be accomplished in soil by driving a pipe into the ground (or placing a pipe in a grouted drill hole) and affixing the plate to the top of the pipe.

It is extremely important to align one set of the measuring pegs with the direction to be observed. Initial readings with the sensor are taken as soon as the grout or epoxy has set.

e. ***Monitoring Procedure.***—Tiltmeters are monitored by placing the sensor on the ceramic plate pegs in the orientation observed at the time of installation then reading the angle directly on the readout indicator in the A position. The switch is then changed to the B position and a second reading is obtained. By use of periodic measurements, the rate of angular deformation can be estimated. The data are recorded on a field data form, as shown on figure 5-2.

f. ***Data Processing and Review.***—The field data are transmitted to the Structural Behavior Branch where processing and review are accomplished as described in section 25. An example of a typical report plot on a tiltmeter installation is shown on figure 5-3.

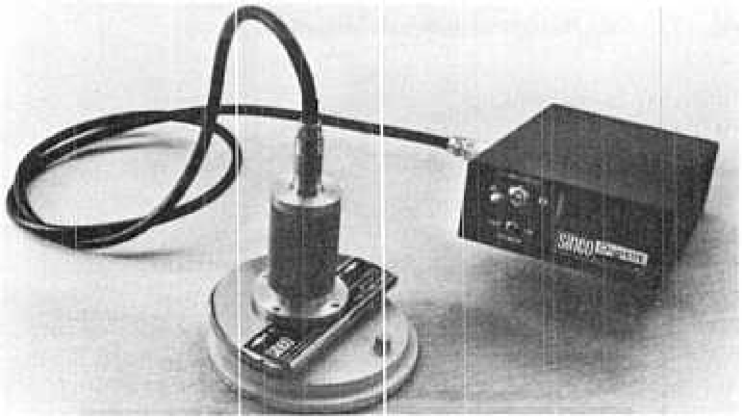
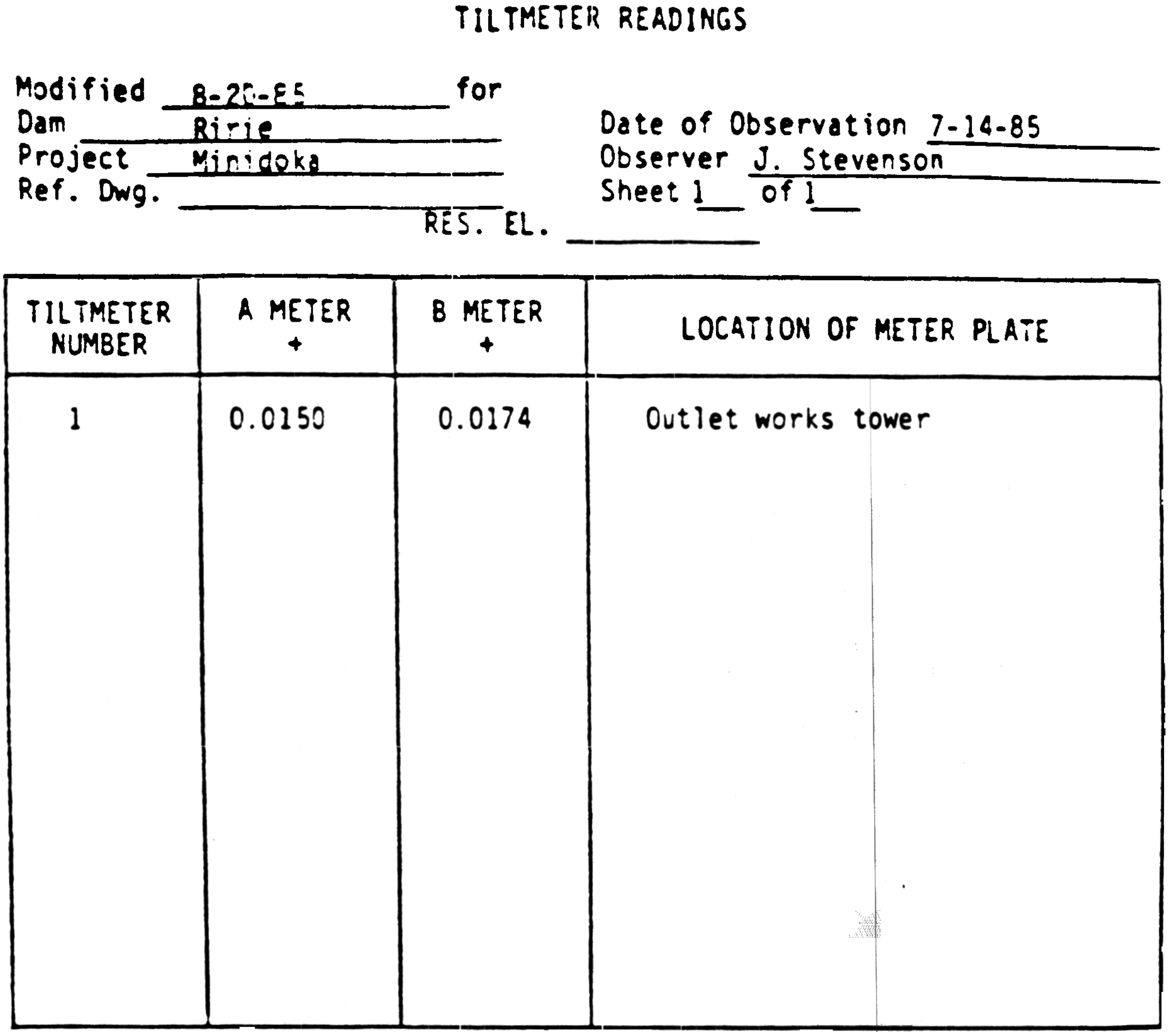


Figure 5-1.—Tiltmeter device. P801-D-81025.



TILTMETER READINGS

Modified 8-20-85 for
Dam Ririe
Project Minidoka
Ref. Dwg.
RES. EL.

Date of Observation 7-14-85
Observer J. Stevenson
Sheet 1 of 1

TILTMETER NUMBER	A METER +	B METER +	LOCATION OF METER PLATE
1	0.0150	0.0174	Outlet works tower

Figure 5-2.—Example form for tiltmeter data.

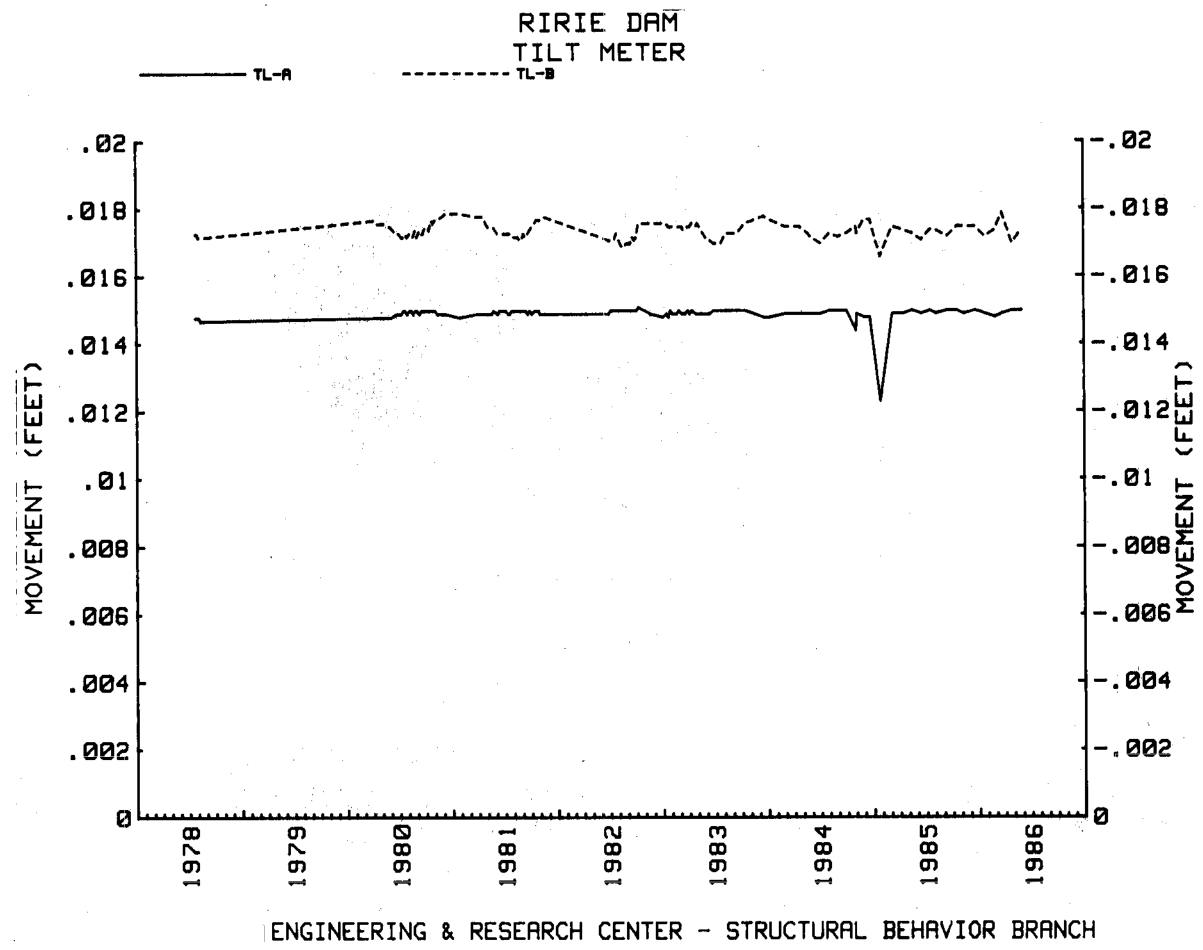


Figure 5-3.—Example plot of surface movement data measured by tiltmeter.

58. Embankment Measuring Points.—a. ***Usage.***—Measuring points are installed on the outer slopes of embankments and abutments to determine the magnitude of total vertical and horizontal movements. Regular periodic readings are then used to indicate the average rate of movement.

b. ***Advantages and Disadvantages.***—Embankment measurement points provide an overall coverage of the movements of a dam as they are reflected at the surface of the embankment. The cost difference between the installation of, say 25 or 50 points, is relatively small. Limitations include the fact that reading the point movement is very labor intensive and must be performed to an accuracy of 0.01 foot. Thus, a continuing significant expense is involved in securing movement data.

c. ***Description of Equipment.***—The measuring devices consist basically of steel pipes or reinforcing bars embedded in concrete in the embankment or abutments. Figure 5-4 illustrates a typical installation. In some of the USBR's regions, large temperature changes occur, and during winter months frost heave can affect measuring points. Figure 5-5 is a typical detail of a cold weather measuring point used in these regions. This type of measuring point is not the only means of dealing with the problem of frost heave, but it has worked well when it has been used. Benchmarks are located off the dam. The measuring points and benchmarks are constructed as construction of the dam progresses.

d. ***Installation.***—The usual rule is that installation of planned measuring points is accomplished as soon as practicable after the outer surfaces of the embankment are raised to an elevation about 10 feet above the elevation of the planned measurement points. The points are preferably installed along straight lines parallel to the crest of the dam. In the case of a curved dam face, the lines of measuring points are installed along the curved surface at approximately similar elevations. The base of the measuring points must extend below frost depth or be of the double-tube cold weather design. All points should be installed at the same offset distance from the centerline so that horizontal deflection data may be obtained.

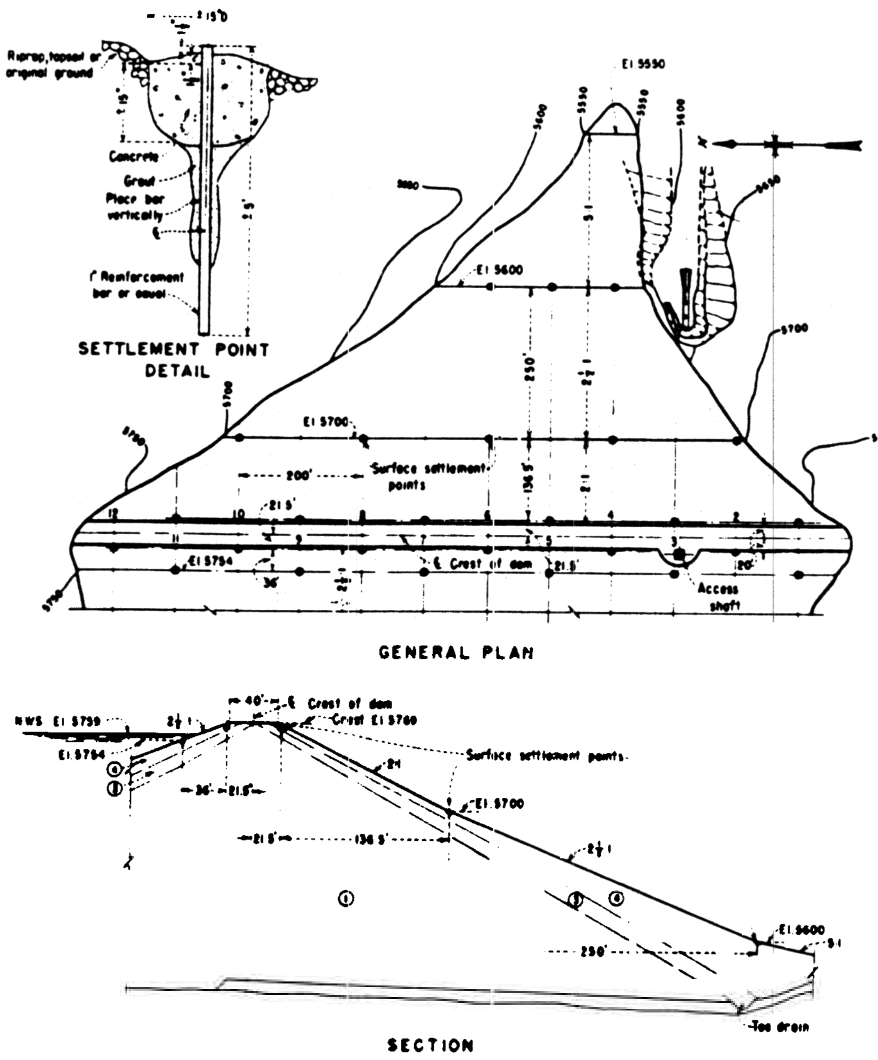
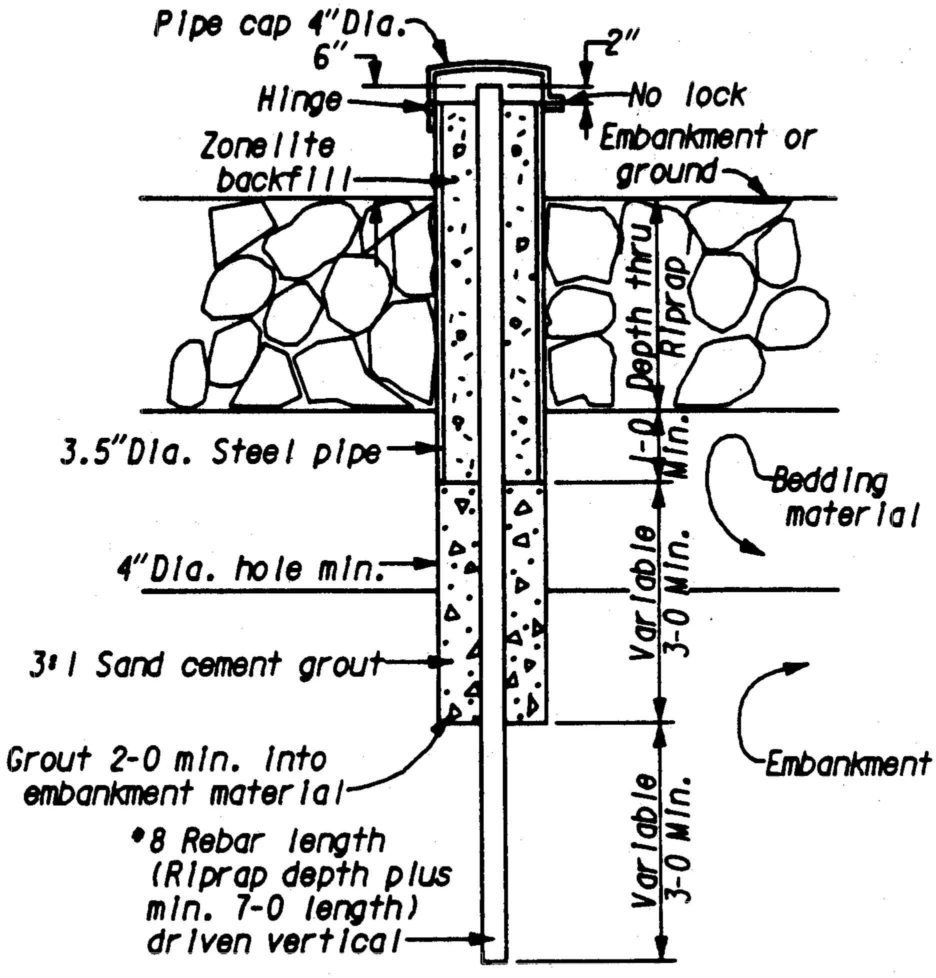


Figure 5-4.—Installation of embankment measurement points. 101-D-326.

Benchmarks are constructed on each abutment on stable ground areas. Construction consists of excavating a hole that is approximately 15 inches in diameter and 3 feet in depth or deeper, depending on the maximum frost depth in the area. A benchmark is set in the concrete backfill as shown on figure 5-6. On the opposite abutment, a benchmark with a target is installed. Construction consists of excavating a hole 5 feet long by 3 feet wide by 4 feet deep and backfilling it with concrete. A benchmark is installed in the center with a target assembly centered over the benchmark. When installing the benchmarks and targets, the following guidelines should be observed: (1) the benchmarks should be installed before installation of embankment measurement points; (2) benchmarks must be visible from one another; and (3) the target dimensions can vary according to the length of the line of sight.

It is customary to place one row of measuring points on each edge of the dam crest. Typical installations may call for spacing at 200-foot intervals along each side of the crest with the points staggered at 100-foot intervals on opposite sides. At least one row of points is usually installed on the upstream face (above maximum pool elevation). Occasionally, a row of measuring points on the upstream face is planned for observation only during construction. As the reservoir fills, these points are no longer used unless the reservoir elevation is lowered for other reasons. The downstream face may contain as many rows of points as determined to be necessary. Embankment points and benchmarks must be protected from damage during and after construction.

At several recent dam construction sites, trilateration control monuments have been installed. Trilateration control monuments are constructed on each abutment on stable ground areas. Details of a typical control monument are shown on figure 5-7. Construction consists of drilling an 8- to 10-inch-diameter hole to a depth



NOTE: Measurement points installed either before riprap is place then hand place riprap or excavate riprap and place bar.

Figure 5-5.—Embankment measurement point installation (cold-weather installation).

below frost line or to a 5-foot depth, whichever is greater, and driving a 2-inch-diameter pipe at least another 2 feet below the bottom of the drilled hole. If rock or hard ground is encountered, it may be necessary to predrill a 1⅞-inch-diameter hole for the pipe to the proper depth. The hole is then filled with concrete to a level 1 to 2 feet above the ground surface using suitable forms. A concrete pad is then constructed around the monument. Monuments should be installed so that they are as visible from the other control monuments as practicable. Embankment measuring points are constructed in a manner similar to control monuments except that the points normally do not extend significantly above the surface and do not usually have a surrounding concrete pad.

e. *Monitoring Procedure.*—The USBR has used a relatively simple means to monitor embankment measuring points both for differential leveling (monuments) and for alignment measurements (deflections upstream or downstream). These methods have proved satisfactory for a long time. As described in the installation procedures, brass caps or benchmarks are installed on the abutments of the dam on stable ground. Both the settlement and deflection surveys are based on those benchmarks. After a row of points or a series

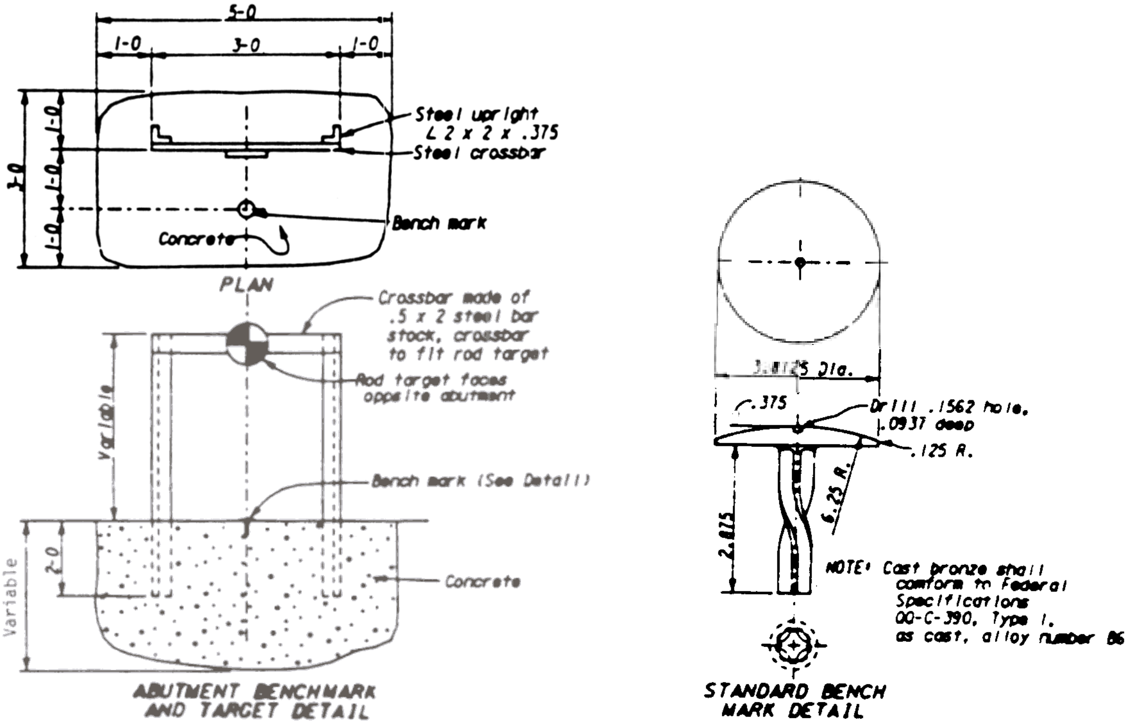


Figure 5-6.—Concrete benchmark installation, typical details.

of points along a given row have been installed, the as-built elevations and offsets (original) from the centerline of the crest of the dam should be determined to the nearest 0.01 foot. At least two surveys should be used to determine initial positions.

Benchmarks for a line of measurement points should be referenced to the centerline of the crest of the dam. Offsets for individual measurement points from an established line between benchmarks should be recorded. However, when the centerline of the crest is curved, as-built elevations should be established to the nearest 0.01 foot for all points. Original alignment control can be established only for selected points, which can be referenced conveniently to targets that may or may not be parallel to the centerline of the crest. The greatest disadvantage with the USBR's method of alignment surveys is that only selected points on curved dams can be monitored. The second disadvantage is the fact that the measurements made on long dams (length over 3000 feet) became very difficult. Typical alignments are monitored by placing the surveying instrument over one abutment benchmark and sighting across to the opposite benchmark (with target) on the other abutment. Lateral deviations from plumblines held at each measuring point are then noted. The elevation of each point is also determined by standard leveling techniques.

The accuracy required by the USBR's typical survey can be stated as second-order (class II), or 1 part in 10,000. This accuracy has proved to be satisfactory in monitoring embankment dams. With the new advancements in survey equipment and methods, the USBR has used a method called trilateration on selected dams. This method measures vertical angles and slope distances to calculate both settlement and deflection data. It has proved to be satisfactory at dams where large areas of an abutment have the potential of moving, where the dam has been constructed with a curve along the centerline, or where long distances are required between control points. Some limiting features of trilateration are the initial cost of survey equipment, the construction and cost of control monuments (fig. 5-7), and the required initial and continuing training of survey crews in the methods required to obtain proper data. The USBR has not yet completely adopted this method of surveying.

The data for the embankment measurement points should be recorded to the nearest 0.01 foot. All field data are recorded on a field data form as shown on figure 5-8. A standard sign convention should always be followed:

- Settlement.—The cumulative settlement of a point is the vertical (downward) movement. Cumulative settlement is indicated without a sign prefix. Heave (vertical movement upward) should be indicated with a minus sign.

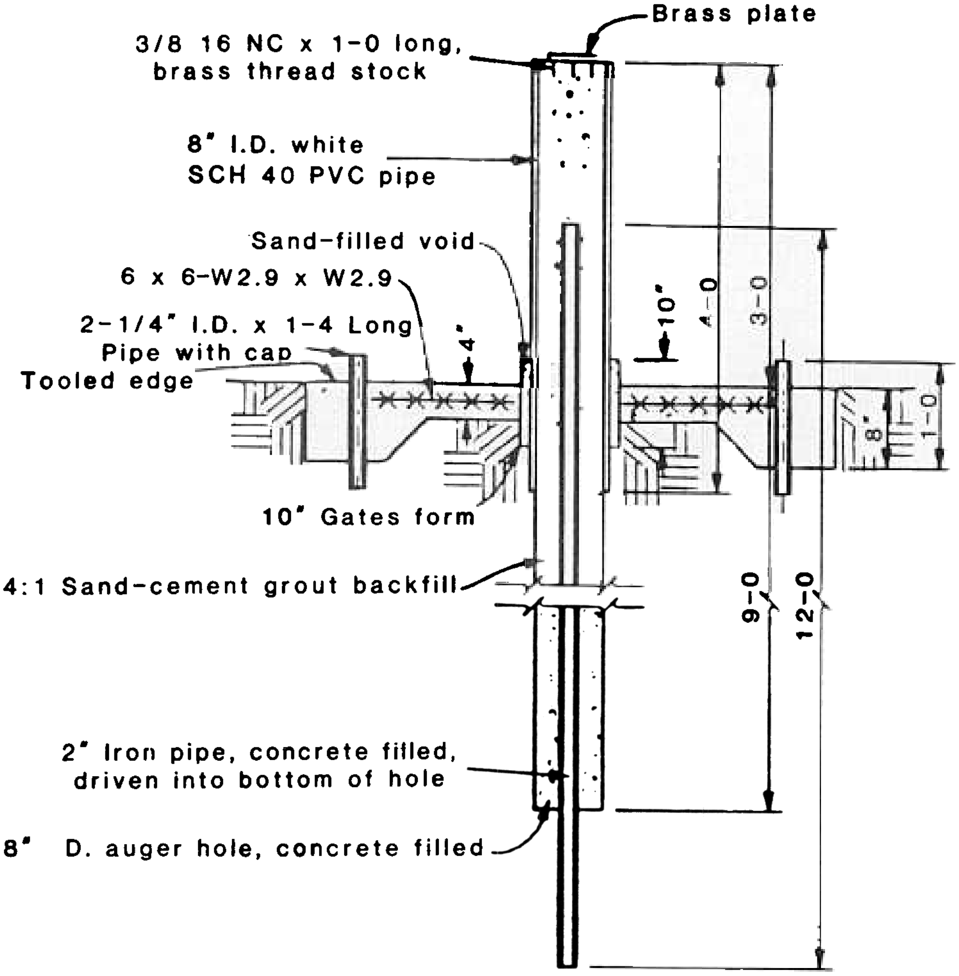


Figure 5-7.—Trilateration control monument installation.

- Deflection.—The cumulative deflection of a point is the horizontal movement or deflection, either upstream or downstream, normal to the centerline of the crest of the dam. Use the abbreviation U/S for upstream and D/S for downstream.

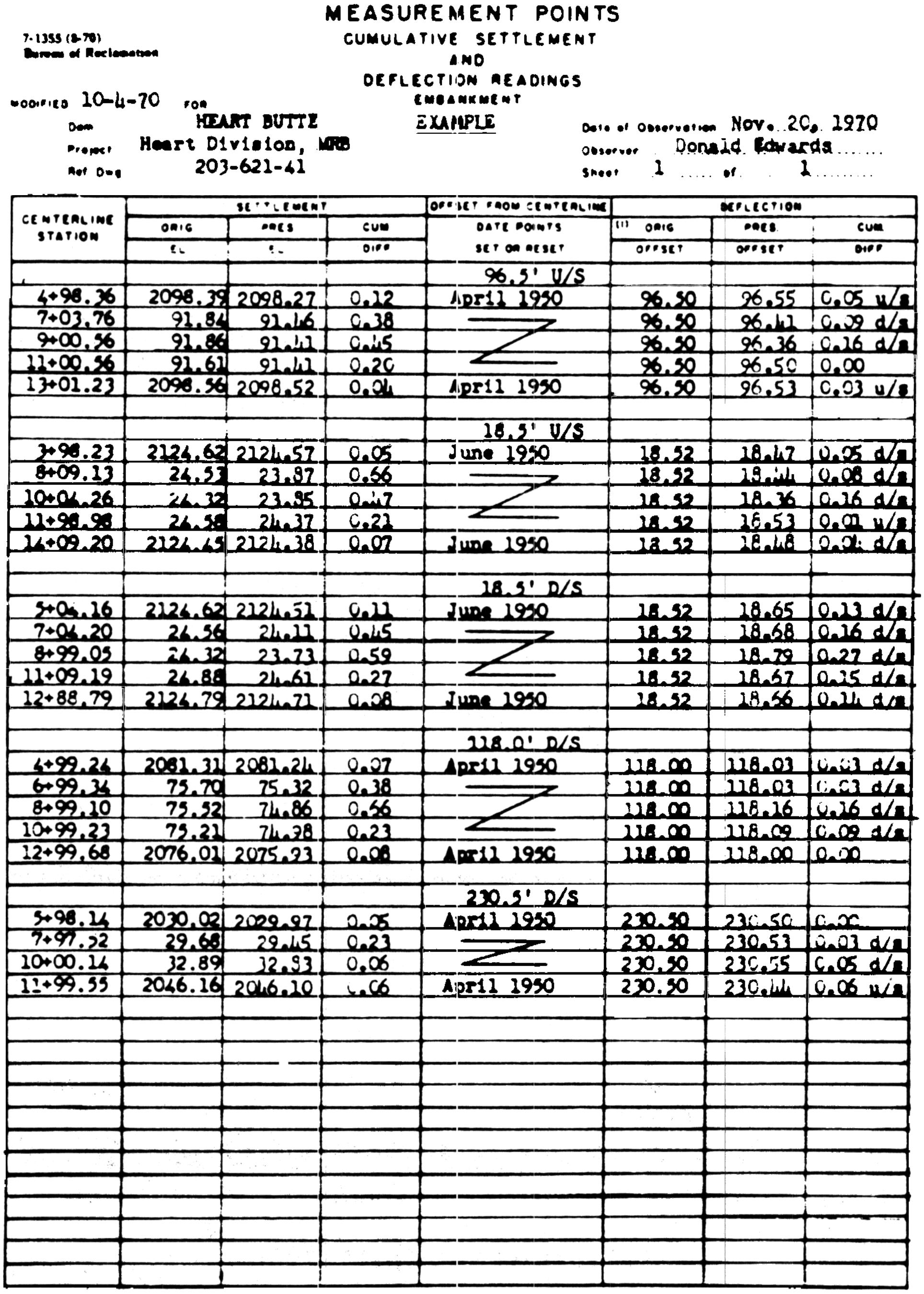
f. ***Data Processing and Review.***—The field data are transmitted to the Structural Behavior Branch where processing and review procedures are conducted as outlined in section 25. Figure 5-9 shows a typical data plot.

59. Structural Measuring Points.—a. ***Usage.***—Measuring points are installed on various structures on a dam to detect total horizontal and vertical movements and to detect structural movement relative to embankment movement. A specific kind of structural measurement (crack measuring) is discussed separately in section 60.

b. ***Advantages and Limitations.***—The advantages and limitations of the use of structural measuring points are essentially the same as those discussed for embankment measuring points in section 58.

c. ***Description of Equipment.***—Structural measuring points may consist of virtually any kind of mark or point set on concrete or other structures from which measurements can be made. However, it is common to utilize ⅜-inch-diameter by 2½-inch-long brass or stainless steel carriage bolts for this purpose. Figure 5-10 illustrates one type of installation.

d. ***Installation.***—Structural measuring points are commonly installed in concrete structure walls or top surfaces. The method of installation is sometimes left to the contractor, but normally consists of carefully setting the points in fresh concrete or in ½-inch-diameter drill holes using epoxy as a grout. The points should be set at locations where movement may reasonably be expected or where movement may result in a critical



7-1355 (8-70)
Bureau of Reclamation

MEASUREMENT POINTS
CUMULATIVE SETTLEMENT
AND
DEFLECTION READINGS
EMBANKMENT
EXAMPLE

MODIFIED 10-4-70 FOR
Dam HEART BUTTE
Project Heart Division, MRB
Ref Dwg 203-621-41

Date of Observation Nov. 20, 1970
Observer Donald Edwards
Sheet 1 of 1

CENTERLINE STATION	SETTLEMENT			OFFSET FROM CENTERLINE	DEFLECTION		
	ORIG	PRES	CUM	DATE POINTS	(1) ORIG	PRES	CUM
	EL	EL	DIFF	SET OR RESET	OFFSET	OFFSET	DIFF
				96.5' U/S			
4+98.36	2098.39	2098.27	0.12	April 1950	96.50	96.55	0.05 u/s
7+03.76	91.84	91.46	0.38		96.50	96.41	0.09 d/s
9+00.56	91.86	91.41	0.45		96.50	96.36	0.16 d/s
11+00.56	91.61	91.41	0.20		96.50	96.50	0.00
13+01.23	2098.56	2098.52	0.04	April 1950	96.50	96.53	0.03 u/s
				18.5' U/S			
3+98.23	2124.62	2124.57	0.05	June 1950	18.52	18.47	0.05 d/s
8+09.13	24.53	23.87	0.66		18.52	18.44	0.08 d/s
10+04.26	24.32	23.85	0.47		18.52	18.36	0.16 d/s
11+98.98	24.58	24.37	0.21		18.52	18.53	0.01 u/s
14+09.20	2124.45	2124.38	0.07	June 1950	18.52	18.48	0.04 d/s
				18.5' D/S			
5+04.16	2124.62	2124.51	0.11	June 1950	18.52	18.65	0.13 d/s
7+04.20	24.56	24.11	0.45		18.52	18.68	0.16 d/s
8+99.05	24.32	23.73	0.59		18.52	18.79	0.27 d/s
11+09.19	24.88	24.61	0.27		18.52	18.67	0.15 d/s
12+88.79	2124.79	2124.71	0.08	June 1950	18.52	18.66	0.14 d/s
				118.0' D/S			
4+99.24	2081.31	2081.24	0.07	April 1950	118.00	118.03	0.03 d/s
6+99.34	75.70	75.32	0.38		118.00	118.03	0.03 d/s
8+99.10	75.52	74.86	0.66		118.00	118.16	0.16 d/s
10+99.23	75.21	74.98	0.23		118.00	118.09	0.09 d/s
12+99.68	2076.01	2075.93	0.08	April 1950	118.00	118.00	0.00
				230.5' D/S			
5+98.14	2030.02	2029.97	0.05	April 1950	230.50	230.50	0.00
7+97.52	29.68	29.45	0.23		230.50	230.53	0.03 d/s
10+00.14	32.89	32.83	0.06		230.50	230.55	0.05 d/s
11+99.55	2046.16	2046.10	0.06	April 1950	230.50	230.44	0.06 u/s

Figure 5-8.—Typical completed Form 7-1355, Measurement Points. Settlement and deflection readings from embankment measurement points.

situation for the functioning of the dam. These locations should be readily accessible and a clear line must be present to allow measurement between at least two points.

e. *Monitoring Procedure.*—The points may be monitored by simple measuring techniques (using a rule) or by simple or complex surveying techniques as required. Elevations determined must be referenced to benchmarks located off the dam. Tape extensometers, described in section 53, may be used for measurements between relatively close adjacent points. Measurements may be made between two structural points or between

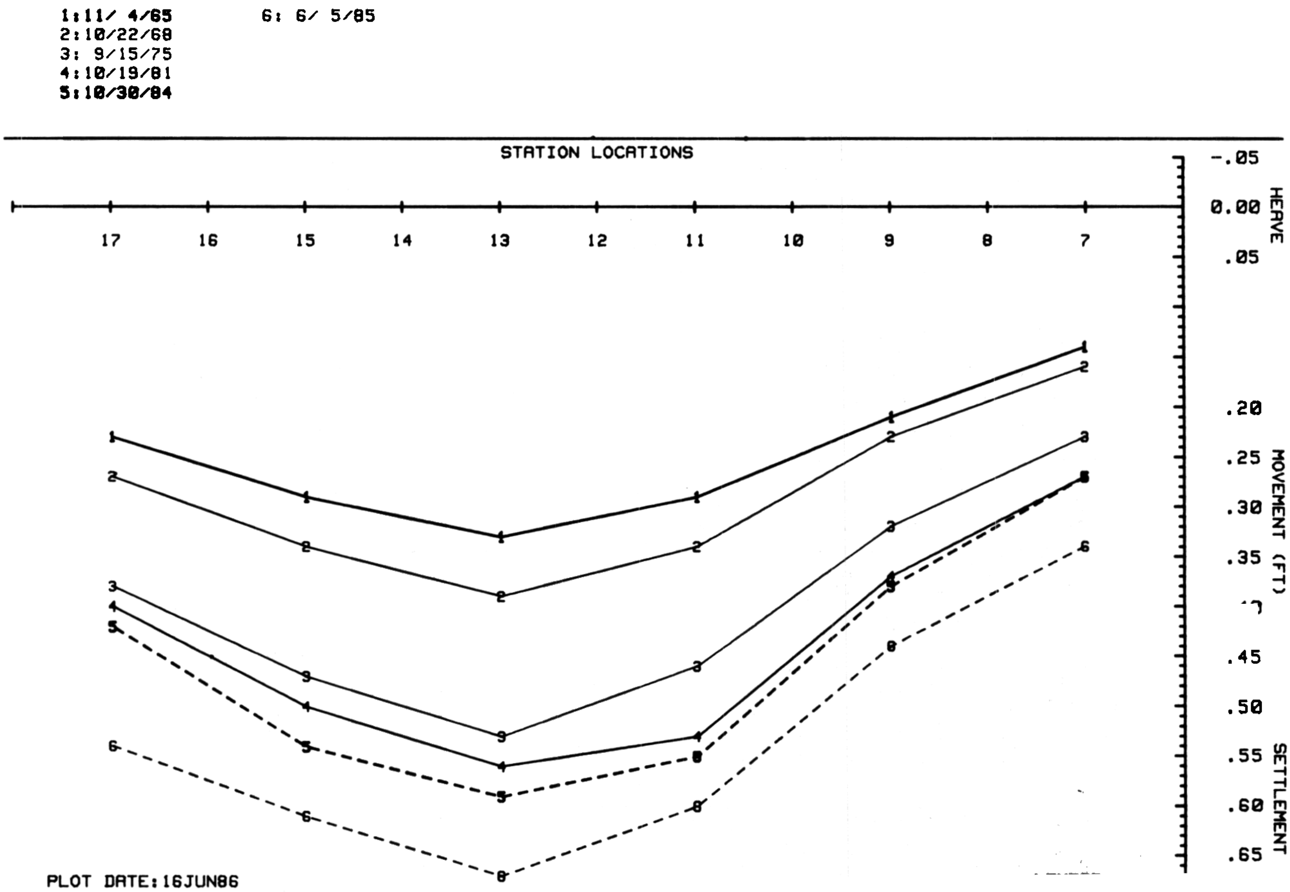
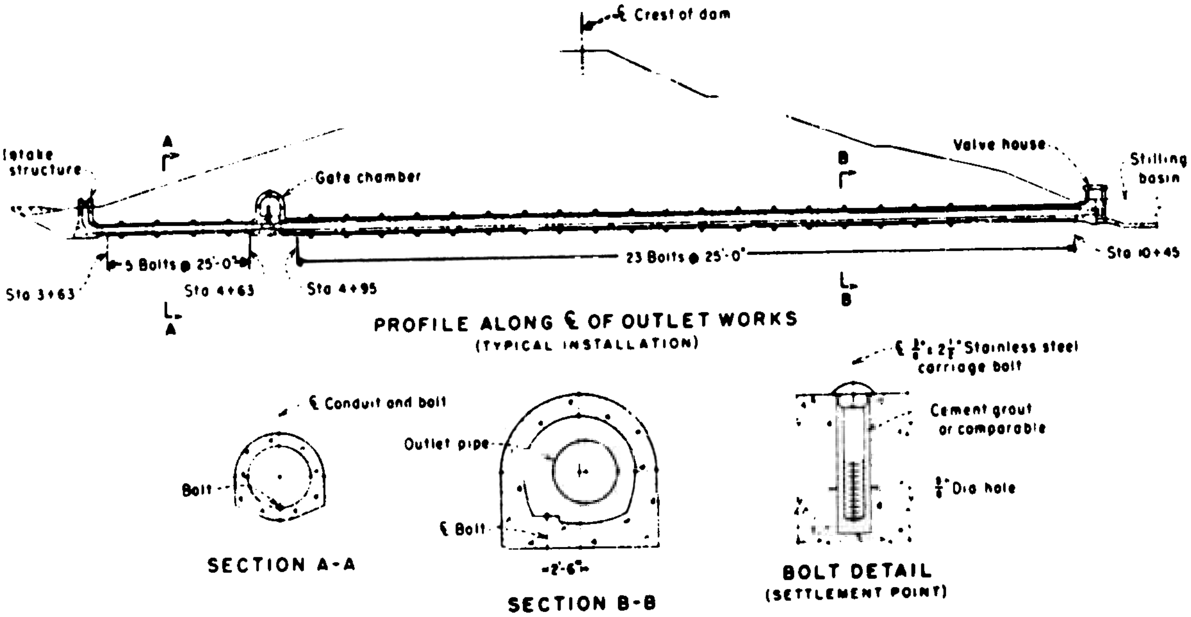


Figure 5-9.—Example plot of surface movement data measured by embankment measurement points.



a structural point and an embankment measuring point. Reporting the settlement of a conduit or spillway measurement point should be indicated using the same sign conventions as for the embankment measurement point described in section 58. If a conduit is measured for deflection, it should be reported with the appropriate abbreviation, U/S OR D/S. Benchmarks to be used for obtaining deflection readings on measurement points located on top of the chute and stilling basin walls of the outlet works or spillways should be located to the left and right of the respective walls (high side).This is so that a reference line can be established and periodic readings made and referenced to the original centerline of the chute and stilling basin.

Data should be reported for deflection of these walls with reference to other points which have moved left (L) or right (R) of their original "as-built" locations. All data should be measured to the nearest 0.01 foot for both settlement and deflection and all left and right movements are referenced while facing downstream. All data are recorded on a field data form, as shown on figure 5-11.

f. ***Data Processing and Review***—Field data are transmitted to the Structural Behavior Branch where data processing and review is conducted as discussed in section 25. Data plots indicating total movement or relative movement are prepared as illustrated by figure 5-12.

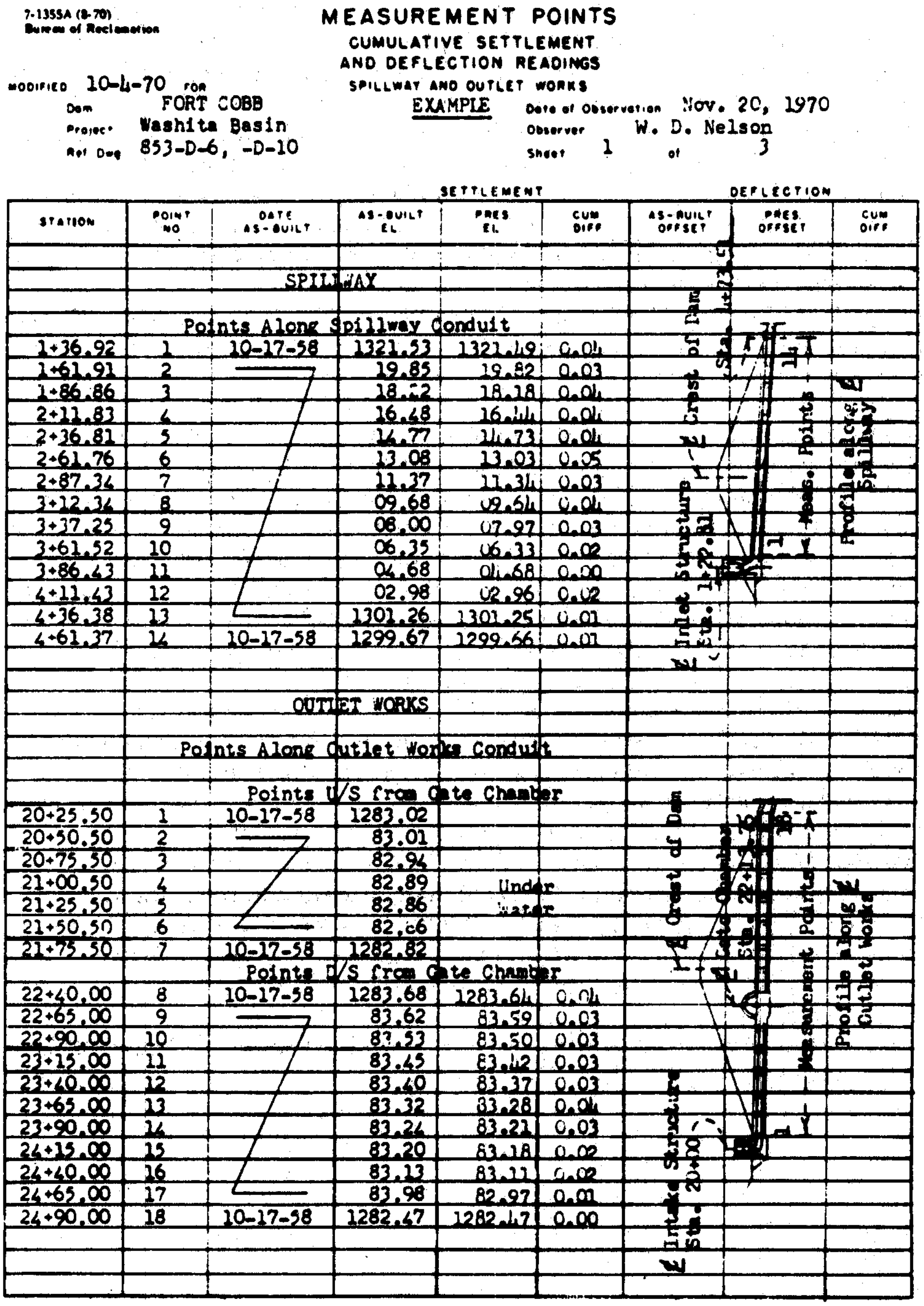
60. Crack Measuring Devices.—a. ***Usage.***—As implied by their name, crack measuring devices are used to measure relative movement of intact masses on either side of a crack or joint. Structural cracks and joints in concrete structures or in conduits on a dam are commonly monitored. Only the relative movement of the material on each side of a crack is measured unless a supplemental structural measuring point is located nearby. In that case, total movement of both sides of the crack may then be determined.

b. ***Description of Equipment.***—Crack measuring devices range from simple marks or points set on each side of a crack (so that measurement of the distance between the points may be made) to patented accurate devices, such as the Avongard calibrated crack monitor, which indicate movement in two planes rather than only one plane. The Avongard device is shown on figure 5-13.

c. ***Installation.***—Simple scratch marks on either side of a crack to be measured may suffice, but it is more common to set small metal plugs or bolts with epoxy in drilled holes (or install crack monitoring self-reading devices) with fixed ends on both sides of a crack or joint. At the time of installation, very accurate measurement of the distance between the points is made. This measurement must serve as the basis for all future measurements. Periodic readings indicate the average rate of movement.

d. ***Monitoring Procedure.***—Monitoring all but the self-reading devices is accomplished by very accurately measuring the distance between the two points located on opposite sides of the crack. Although it is desirable to measure to an accuracy of 0.001 inch, it is usually acceptable to measure to an accuracy of 0.01 inch. Self-reading devices may be read and recorded along with the date, or they may be photographed and the photograph properly labeled with the date and location of the device. All field data are recorded on a field data form, as shown on figure 5-14.

e. ***Data Processing and Review.***—The field data are transmitted to the Structural Behavior Branch for processing and review, as described in section 25.



7-1355A (8-70)
Bureau of Reclamation

MEASUREMENT POINTS
CUMULATIVE SETTLEMENT
AND DEFLECTION READINGS
SPILLWAY AND OUTLET WORKS

MODIFIED 10-4-70 FOR
Dam FORT COBB
Project Washita Basin
Ref Dwg 853-D-6, -D-10

EXAMPLE

Date of Observation Nov. 20, 1970
Observer W. D. Nelson
Sheet 1 of 3

			SETTLEMENT			DEFLECTION		
STATION	POINT NO	DATE AS-BUILT	AS-BUILT EL	PRES EL	CUM DIFF	AS-BUILT OFFSET	PRES. OFFSET	CUM DIFF
		SPILLWAY						
		Points Along Spillway Conduit						
1+36.92	1	10-17-58	1321.53	1321.49	0.04			
1+61.91	2		19.85	19.82	0.03			
1+86.86	3		18.22	18.18	0.04			
2+11.83	4		16.48	16.44	0.04			
2+36.81	5		14.77	14.73	0.04			
2+61.76	6		13.08	13.03	0.05			
2+87.34	7		11.37	11.34	0.03			
3+12.34	8		09.68	09.64	0.04			
3+37.25	9		08.00	07.97	0.03			
3+61.52	10		06.35	06.33	0.02			
3+86.43	11		04.68	04.68	0.00			
4+11.43	12		02.98	02.96	0.02			
4+36.38	13		1301.26	1301.25	0.01			
4+61.37	14	10-17-58	1299.67	1299.66	0.01			
		OUTLET WORKS						
		Points Along Outlet Works Conduit						
		Points U/S from Gate Chamber						
20+25.50	1	10-17-58	1283.02					
20+50.50	2		83.01					
20+75.50	3		82.94					
21+00.50	4		82.89	Under				
21+25.50	5		82.86	water				
21+50.50	6		82.86					
21+75.50	7	10-17-58	1282.82					
		Points D/S from Gate Chamber						
22+40.00	8	10-17-58	1283.68	1283.64	0.04			
22+65.00	9		83.62	83.59	0.03			
22+90.00	10		83.53	83.50	0.03			
23+15.00	11		83.45	83.42	0.03			
23+40.00	12		83.40	83.37	0.03			
23+65.00	13		83.32	83.28	0.04			
23+90.00	14		83.24	83.21	0.03			
24+15.00	15		83.20	83.18	0.02			
24+40.00	16		83.13	83.11	0.02			
24+65.00	17		83.98	82.97	0.01			
24+90.00	18	10-17-58	1282.47	1282.47	0.00			

Figure 5-11.—Typical completed Form 7-1355A, Measurement Points. Settlement and deflection readings from structural measurement points.

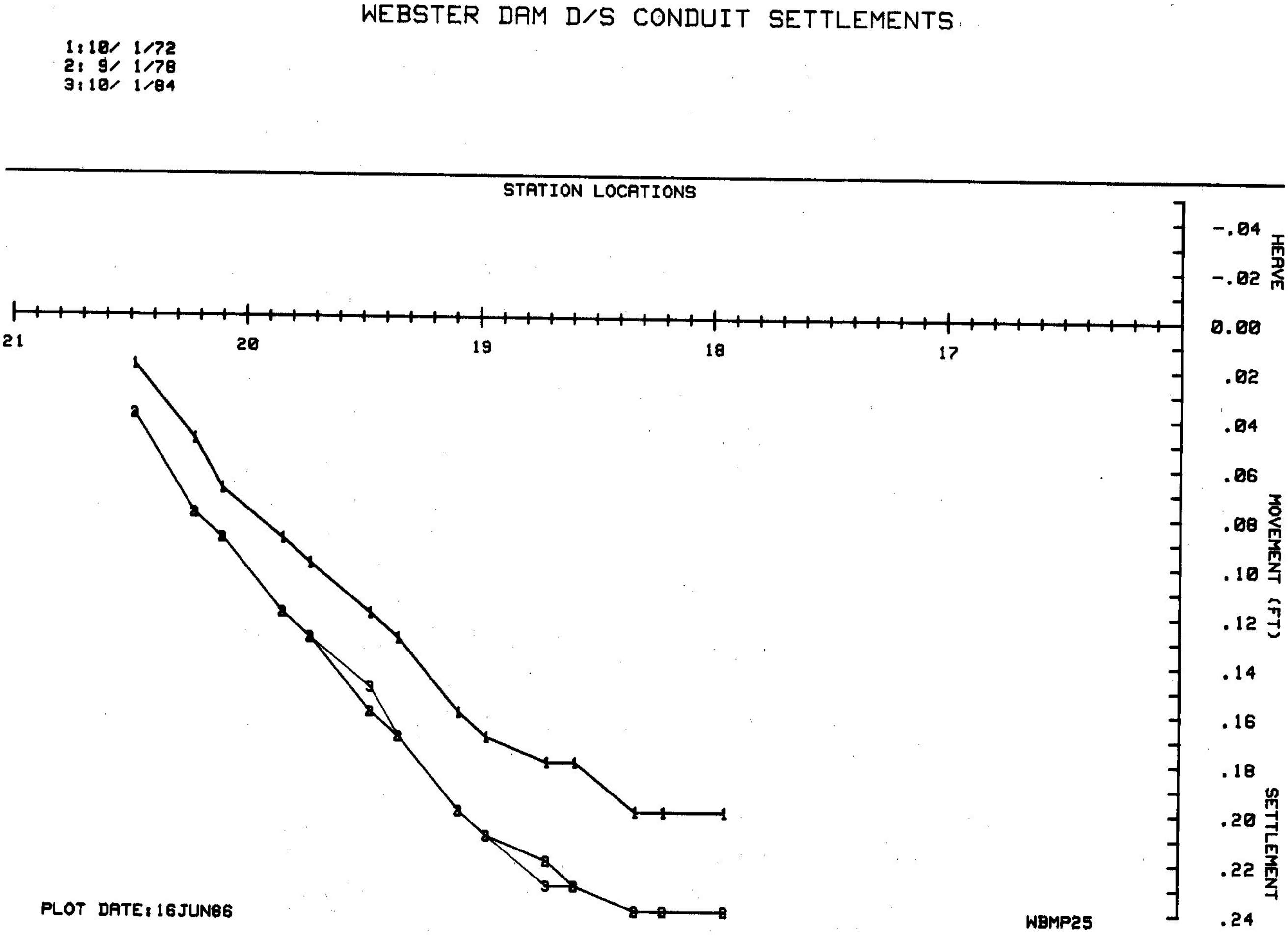
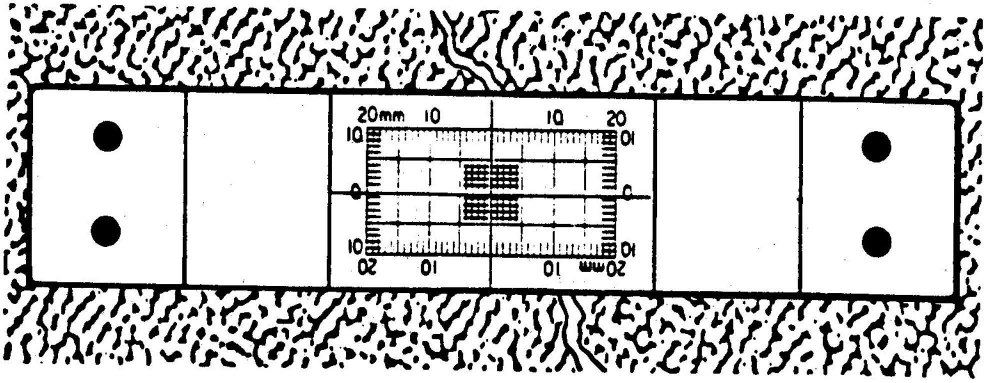
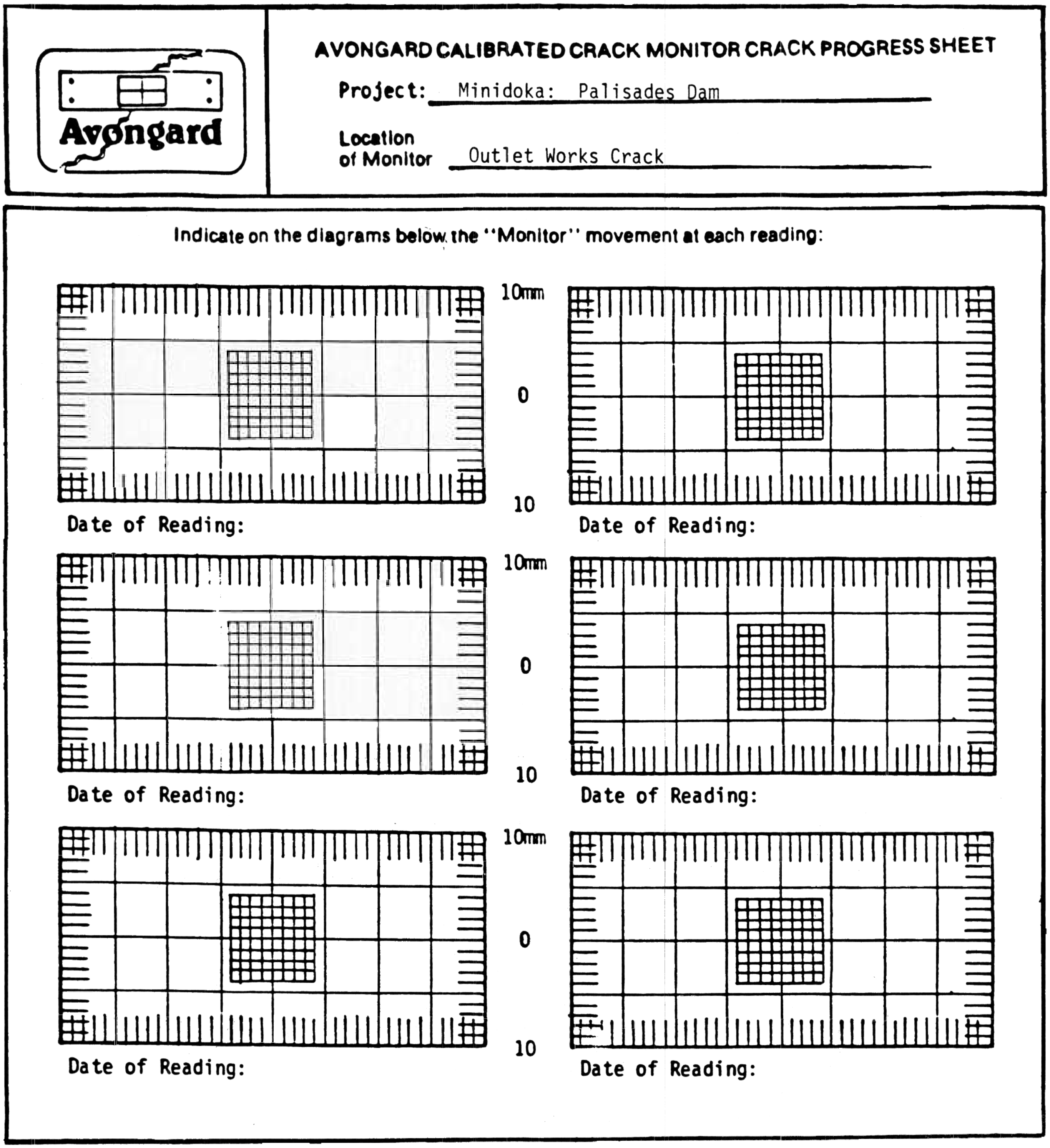


Figure 5-12.—Example plot of surface movement data measured by structural measurement points.



When newly mounted, the Monitor will appear as shown above.

Figure 5-13.—Calibrated crack monitor.


AVONGARD CALIBRATED CRACK MONITOR CRACK PROGRESS SHEET

Project: Minidoka: Palisades Dam

Location of Monitor: Outlet Works Crack

Indicate on the diagrams below the "Monitor" movement at each reading:

Date of Reading:

Date of Reading:

Date of Reading:

Date of Reading:

Date of Reading:

Date of Reading:

Figure 5-14.—Example field data form for calibrated crack monitor measurements.

Chapter VI

VIBRATION MEASURING DEVICES

A. History and Development of Devices

61. General.—Vibrations at damsites may be classified into either of two principal categories: natural vibrations caused by earthquakes or tectonic movements and induced vibrations created by construction activities. The effects of both categories of vibration are identical, but the magnitude and scale of the vibrational force may differ a great deal. The possibility of damage such as cracking of structures or liquefaction of dam foundations represents a serious condition and an obvious threat to the stability of a dam. Currently, there are no means of controlling earthquake occurrences or of making accurate predictions concerning their occurrence. There have been, however, positive developments in vibration theory and analysis that are becoming commonly accepted as methods to provide control limitations on construction blasting. Vibration theory and analysis can aid in the determination of the acceptable amount of explosives, the appropriate number and timing of delays, and other essential blasting considerations.

The intensity and duration of ground vibrations that a structure can tolerate without experiencing damage are quite variable. Such physical factors as material type, material density, water content, and natural frequency create the variations that exist in ground vibrations. Not only does physical property variability create problems, but the parameters that best describe the intensity of ground motion necessary to create structural damage, such as maximum displacement, maximum particle velocity, maximum acceleration, and frequency, may be difficult to determine. The maximum particle velocity is now the parameter used most extensively as a correlation tool with potential structural damage. Correlation charts are available for anticipated damage levels related to particle velocity.

62. Types of Devices.—Seismic instruments were first developed in the 1930's; however, most technological advances have occurred in the past 10 to 15 years. Over the past 50 years, a number of vibration measuring devices have been developed. The seismograph is the most commonly used seismic instrument of the devices available; this includes the seismometer, the accelerograph, and the accelerometer. Although these devices are generally very similar, the main distinction between them is that a seismometer (accelerometer) is a vibration sensor and the seismograph (accelerograph) is a recording device that records a graph of a seismic record. Nearly all seismic instruments in use today use servo-accelerometers, which can measure motion in a single horizontal, vertical, or transverse plane. The USBR uses the term "strong-motion earthquake instrument" for instruments that record significant vibration, as opposed to microseismic activity, which requires the use of signal conditioners or enhancers to magnify the motion to a recordable level.

The first strong-motion instrument installed by the USBR in an embankment dam was at Bradbury Dam[1] in 1954. The USBR has installed strong-motion earthquake instrumentation since 1937, beginning with Hoover Dam. Since 1954, 20 additional embankment dams have been instrumented, and others are planned.

To develop the methodology and loading conditions and to verify the results of dynamic analyses, much data are needed on the nature of strong ground motion resulting from earthquakes and on the performance of structures (especially dams) subjected to earthquake loading. Such data and analyses can be used in the design of new dams and in the modification of existing dams to make them withstand earthquake loadings appropriate to their locations. In the early 1970's, the USBR initiated a program to replace the existing old-type instruments in USBR structures with new strong-motion accelerographs and to instrument additional new and existing structures. By 1975, all of the early U.S. Coast and Geodetic Survey type instruments installed on USBR structures were replaced by modern, self-contained three-component mechanical-option accelerographs. These new instruments are more reliable, and recent modifications and innovations in time coding, power supplies, and installations (borehole as well as surface shelters), now allow measurement of response to earthquake strong motions in almost any climatic environment at any location within a structure.

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[1] Bradbury Dam is a zoned earthfill dam, 279 feet high and 3,350 feet long, located on the Santa Yuez River in Santa Barbara County, California.

B. Currently Used Devices

63. Strong-Motion Earthquake Instruments.—a. *Usage.*—Strong-motion earthquake instruments, or (generically) "vibration monitoring devices," are being deployed at selected dams and other water-resource related structures and will likely continue to be installed for many years to come. Discussions of site selection factors for strong-motion instruments and the distribution of such instruments in the United States have been made by Viksne [84] and Hudson [40]. The present goal of the USBR's strong-motion program is to continue deploying instruments considering the following factors:

- Seismic zoning and proximity to faults capable of causing earthquakes
- Dimensions of the dam and reservoir
- Foundation materials
- Method of construction/type of dam
- New versus existing dams
- Water-resource life-line features or special interest

The most important factor controlling the USBR's instrumentation program is the location within prioritized seismic zones. The USBR uses the Uniform Building Code (1982) Seismic Zone Map as the basic guideline for this purpose. There is no doubt that such zoning is very broad, and that there are "zones within zones" that must be considered in the USBR's sequential deployment of strong-motion instruments. Within zones 3 and 4, the zones of highest instrumentation priority, dam locations may vary greatly in respect to proximity of faults capable of causing earthquakes and earthquake magnitude and recurrence exposure levels. Within seismic zone 4 in California, for example, the USGS (Geological Survey), the CDMG (California Division of Mines and Geology), and the University of Southern California have located arrays of strong-motion instruments where historical seismicity indicates strong-motion events will occur in the relatively near future. An example of subzone of seismic zone 3, where the USBR considers significant seismicity possible during the lifetime of its dams, is in east-central California, where Boca, Stampede, and Prosser Creek Dams are located. Both Boca and Stampede Dams have been instrumented for a number of years, and the instrumentation of nearby Prosser Creek Dam is planned.

The basic program with regard to zoning requires the installation of strong-motion instruments on all exisiting storage dams in seismic zone 4 and on most of the significant storage dams in seismic zone 3.

Newer dams, outside of seismic zones 3 and 4, have been planned for strong-motion instumentation because of engineering concerns for a complete suite of dam instumentation, including strong motion. This concern may occasionally transcend seismic zone boundary and seismic exposure considerations. USBR instrumentation planning does, however, take into account site-specific detailed seismotectonic studies through the Western States that are done by the USBR, other agencies, and private industry. These studies are extending the knowledge of causative earthquake structures such that existing seismic zoning, in terms of magnitude and seismic recurrence to be expected, will require modifications and refinements. The USBR, therefore, views seismic zone maps as state-of-the-art guidelines that can be modified by engineering judgment. Strong-motion instrumentation, as related to water resource structures throughout the Western States, is concentrated in seismic zones 3 and 4, but still widely distributed throughout seismic zone 2.

The present USBR practice is to consider seismic zoning as the predominant siting factor, but size, foundation materials and method of construction are other parameters that may influence strong-motion instrument siting priorities. Foundations that contain unconsolidated silts or fine-grained sands and are, therefore, potentially liquefiable are important considerations. Hydraulic fill structures are vulnerable to failures under strong ground motion and may be prioritized for instrumentation over earth embankments placed with modern compaction methods.

b. *Types of Devices.*—(1) *Free-Field Instruments.*—A number of sites that the USBR has instrumented have only free-field installations. It is recommended that free-field instruments be installed near both abutments and at the toe of an ideal dam; such instrumentation should be placed at a distance beyond any significant influence of the dam on the recorded ground motion. For structural analyses purposes, the USBR does not require these optimal free-field installations, nor does it deliberately attempt to deploy free-field instrumentation. It relies instead on other agency network installations. Some of the USBR installations are free-field simply because of access or siting limitations around the dams, especially downstream. There are a large number of dams in the United States with nearby free-field instruments; for example, in California. More study is required to determine the extent of the influence of large structures, such as dams and their concomitant reservoir loads and ground-water effects, on ground motion to be certain of structure-independent free-field sites.

(2) *Input Motion Instruments.*—The USBR locates the input motion components of the strong-motion array at the downstream toe and on the abutments as close to the dam as possible. Most of these instruments are placed in prefabricated housings on concrete pads firmly secured to the underlying rock or surficial material. The field review of a few typical dams selected at random will demonstrate that exterior siting is difficult at the toes of most dams because of backwater from downstream reservoirs, tailwater from power plants, spillway basin, plunge pools, outlet works, or other features not amenable for instrumentation sites. Similar conditions can exist at the dam/abutment contact area where topographic and access considerations frequently allow little room for satisfactory instrument sites. In the abutment areas, an ideal installation in a spatially restricted area would be a small chamber in the natural material where maintenance problems could be minimized. Interior or subsurface input motion sitings consist of borehole instrumentation in the foundations of earth dams and installations in selected galleries of concrete dams. Drainage and grouting galleries, when excavated in earth dam foundations, can be used as input motion sites for strong-motion instruments.

Many USBR dams are built on deep deposits of unconsolidated surficial materials in the bottoms of valleys and canyons. If such deposits represent the typical foundation conditions at the base of a dam, then care is taken to locate the input motion instrument on the surficial materials and not, for example, on bedrock that might be outcropping in the area.

(3) *Response Instruments.*—The USBR ideally installs one or two response instruments on the crest of both earth and concrete dams. The primary location is where maximum deformation during strong motions is expected, which is usually at the maximum section. A secondary location may be about one-third of the crest length from an abutment. The secondary location is basically for backup purposes. Many USBR dams are asymmetrical because of differences in abutment slopes, stream channels not in the center of the valley, or other topographical features related to geologic structures. The maximum section, therefore, may be far from the actual center of the dam crest.

If a dynamic analysis of structure has been done before strong-motion instrument deployment, the response instrument locations may be specified based on the analysis. Specified areas would be where lower safety factors and higher loads are expected. These locations would be site-specific for each structure and for earth dams, depending on: (a) the zoning geometry of the dam, (b) the types of materials used in the zones; and (c) the nature of the foundation.

c. ***Description of Equipment.***—Vibration monitoring devices consist basically of three components; a sensor, a signal conditioner, and a recorder, or storage medium.

(1) *Sensor.*—The sensing devices used are electro-mechanical units that respond to motion and produce an electrical signal that is, within limits, proportional to displacement, velocity, or acceleration. Most sensors are models of single degree of freedom spring-mass-dashpot systems. The measurement is usually made of the spring extension or compression with the resonant frequency and the damping of the system so proportioned as to produce an electrical signal that is an analog of either acceleration, velocity, or displacement.

Examples of this type of system include accelerometers and velocity gauges where the spring system is an elastic member with electrical strain gauges attached, and the damping is provided by oil immersion or eddy-current systems; piezoelectric accelerometers where the spring is an elastic piece of piezoelectric material and the unit is almost undamped; and servo-accelerometers where the effective spring is a separate electronic system that generates a restoring force similar to that of a spring.

Many other sensor types, which differ in detail from those described, are available. Variable inductance, variable capacitance, variable resistance, etc., or nearly any electrical parameter may be used for the conversion of motion to an electrical analog. However, gauges that do not use the relative displacements of a spring-mass-dashpot system require a fixed point of reference. This requirement severely limits application of this type of gauge.

The limits of operation of the single degree of freedom model gauges are usually those of minimum detectable amplitude (sensitivity), maximum amplitude (loss of linear response or mechanical damage), and usable frequency range. It should be noted that some sensors may be advertized as usable between two given frequency limits with no accompanying warning to the user that the sensor has a highly resonant response above or below those limits. This resonant response must be suppressed by a signal conditioning unit.

To determine the total vector quantity of motion at a point, three orthogonal sensing units are normally included in a sensor unit. The magnitude of the motion is the square root of the sum of the squares of the three orthogonal components of motion.

Sensors may be located at the recording unit or placed in a remote location in a drill hole or elsewhere. Signals are transmitted via a coaxial cable to the signal conditioner. It is common for sensors to contain a starter or triggering device which activitates the sensor at some predetermined acceleration such as 0.01 gravity. The sensor would then continue to operate as long as the motion was greater than that value and for a short period of time thereafter.

(2) *Signal Conditioner.*—The term "signal conditioner" refers to all units and devices placed between the sensor and the final output data recorder. These devices are usually power amplifers that are required to change the micro-power signal levels from the sensor to the macropower levels required to activate the recorder system. Signal conditioners usually also include sensitivity controls to permit a desired level of recorded signal.

Signal conditioning equipment may also include analog integration units for conversion of one measured parameter to another. The signal conditioner equipment may be physically a part of the sensor unit or of the recorder unit, or it may be separately packaged.

(3) *Recorder.*—The recorder unit is the final device in the system and is located in a protected environment in a secured control house. The recorder presents the output in some usable form for evaluation and/or further use. Most recorders in common use plot the input phenomena versus time as a paper record. Such records provide a quick method of visual inspection and permit a rapid evaluation of peak amplitudes, etc. However, detailed study of data in this form requires laborious point-by-point transcription of values for future computation.

Automatic data handling can be obtained for the use of a magnetic tape recorder and later playback onto computing systems. The most desirable system includes an output of both direct reading paper records for rapid field inspection plus a magnetic tape for direct storage leading to later computer processing. Most recorders also provide a timing base that is recorded along with the sensor signals as a reference for determining the frequency of the vibration.

d. *Operation and Maintenance Considerations.*—Optical-mechanical, self-contained accelerographs that record on 70-mm photographic film are the most widely used strong-motion type worldwide because of their low cost, high reliability, simple operation, and straightforward maintenance/repair procedures. They are preferred over both analog or digital tape and solid-state recording methods; however, improvements in these alternative types continue to be made. After triggering, up to 25 cumulative minutes of motions equal or stronger than 0.01 *g* can be stored. In most units, recording continues for 10 seconds after motions drop below the 0.1-*g* level.

Several calibration tests, both laboratory and field, must be conducted before the instruments are installed. Instrument sensitivity calibration, or the deflection of the seismograph trace under 1.0 *g* loading, is generally performed by the manufacturer under laboratory conditions before the equipment is brought to the field. Calibration tests for damping and natural frequency are easily performed in the field. These calibration tests are recorded at the beginning and end of each roll of film.

Two timing traces are continuously recorded with the earthquake ground motions. One of these traces is always a square wave pulse produced internally. The second trace may be another square wave pulse, a binary time code controlled by an oscillator and set according to an external clock, or, more commonly, a Bureau of Standards radio signal time code. The timing is necessary so that each motion event can be clearly identified for correlation with events on other records.

USBR strong-motion instruments are maintained on a regular basis. Typically, a technician checks the instrument installation every 6 months and removes the exposed portion of the film if the instrument has been triggered. If a strong-motion event has been recorded, the USBR routinely digitizes the analog record, corrects for film distortion, variable film speed, and instrument response, and filters the record to remove long period noise.

The maintenance of the USBR's strong-motion arrays is complicated by the diversity of the sites, with extremes such as high elevations and very cold to very hot climates. Both heat and cold are dealt with: the addition of sunroofs and improved air circulation by venting has lessened heat problems and electric heating and insulated shelters have dealt with extremely cold conditions. Drainage is an important aspect of surface instrument sites; poor drainage has temporarily caused operational problems and shutdowns. In attempts to locate instrument housings out of the way of access roads and work areas, the housings have been located close to cut slopes. However, sloughing material and minor slides have interfered with operations at these sites. Small concrete revetments now protect several housings.

e. ***Monitoring Procedure.***—The monitoring procedure consists of securing the paper records of the tracings from the data recorder on a periodic basis. Additional data are secured from the recorder immediately following known seismic events.

f. ***Data Processing and Review.***—The data are analyzed by USGS personnel in conjunction with USBR personnel from the Geophysics Section of the Geology Division. If the data indicate a problem at a damsite, the procedures for review and emergency action described in section 25 are followed.

Chapter VII

SPECIAL SUPPLEMENTAL MEASUREMENTS AND DEVICES

A. Special Measurements

64. Water Quality Testing.—a. ***Purpose.***—Water quality testing is conducted on water samples obtained from many USBR damsites. The usual reason for conducting a water quality testing program at a dam is the desire to compare the characteristics of seepage water with the characteristics of the reservoir water. Such comparisons may be valuable in the detection of important factors affecting the safety of dams. These factors include:

(1) Possible solutioning of foundation or abutment rock or chemically bound aggregated soil materials. Solutioning (the process whereby water flowing through a material chemically dissolves a portion of that material) can result in a weakening of a dam's foundation or abutments and/or increase the size of fissures or cracks where water can flow, thereby leading to increased seepage quantities.

(2) Progressive erosion of soil particles from foundations, abutments, or dam embankments. If seepage water contains a large or increasing quantity of soil particles, it is an indication that internal erosion is occurring. Such internal erosion can lead to a form of progressive erosion failure known as piping.

(3) New seepage paths. If flow increases in certain drains, and the water contains new or increased quantities of certain constituents, it is an indication that a new seepage path may have been developed.

b. ***Water Sampling Techniques.***—The information obtained from a water testing program is of no significant value if the sampling techniques used for obtaining the water specimens, the sample handling techniques, and the testing methods are not in accordance with established practices. In fact, erroneous data obtained in a testing program will likely be more detrimental to proper decision making than no data at all. It is, therefore, essential that all phases of the testing program be properly conducted to eliminate any doubt regarding how representative a sample may be and whether it was properly handled and tested. The chemistry laboratory at the E&R Center is available for consultation or field participation to advise on sampling techniques and analysis requests. Field personnel are encouraged to use this pool of expertise.

Recommended sampling, handling, and testing methods are given by ASTM (American Society for Testing Materials), the APHA (American Public Health Association), the EPA (Environmental Protection Agency), the USGS, and others. No attempt will be made in this manual to duplicate or quote those recommendations, except to highlight general guidelines as they affect USBR water testing programs.

(1) *Sample Containers.*—Glass or plastic sample containers in sizes ranging from 1 pint to ½ gallon may be supplied by the chemistry laboratory. These sample containers have been thoroughly cleaned, sterilized, and sealed before shipment to the site. A small piece of tape placed over the container cap will indicate whether the container has been opened (and possibly contaminated) before the actual sampling time. A container that has been previously opened or is not properly sealed should not be used. Field personnel should not attempt to clean or sterilize any sample container for later use in sampling.

(2) *Shipping Containers.*—Sample bottles are shipped or delivered to the damsite in special insulated coolers designed to protect the sample from breakage and to offer protection from freezing or excessive heat. It is intended that the same or similar shipping containers be used for returning the full sample bottles. Regardless of the degree of protection offered by the shipping container against damage, it is important to use all possible care while handling and transporting the samples to minimize the chances of damage. USBR samples should be shipped directly to the chemistry laboratory or to the contract laboratory.

(3) *Sampling.*—The purpose of sampling water at a dam is to enable determination of the exact characteristics (physical and chemical) of the water at the location sampled under the conditions (temperature, flow, etc.) existing at the time of sampling. The sample must, therefore, be truly representative of the water existing at that time and place. Obviously, to accomplish this goal, standard sampling methods must be used, as highlighted in the following paragraphs.

Sampling from observation wells or vertical pipes may be accomplished according to the following procedure:

(a) Determine the existing water level in the pipe and record it on the field data sheet.

(b) Using either a *clean* bailer or a pump, lower the water level in the pipe to the bottom of the pipe or by an amount of at least 10 feet (unless rapid inflow prevents doing this).

(c) Allow sufficient time for the water level to rise at least one-half of the depth removed.

(d) Lower a *clean* sampling device to the desired level and secure a water sample. Many commercial water sampling devices are available. Most devices have a plug or stopper on the sampler that can be removed by pulling a string after the weighted sampler has been lowered below the water surface. Sampling of the water at the surface should not be attempted to avoid sampling any floating debris, oil, etc., on the water surface.

Sampling from protruding drain pipes or from free-flow weirs should be accomplished by sampling directly into a sample container held by hand or by an extension arm that is manipulated by hand. The container should be drawn across the entire width of flow from the pipe or weir with quick sideways motions until the container is filled. It is important to determine the flow rate at the time of sampling and enter that data on the field data form.

Sampling from open channels, ditches, or open drains should be preceded by a determination of the flow rate. Water sampling is then accomplished directly into a hand-held sample container (in the case of a small channel or low flow). Where personal access is restricted, a mechanical extension arm may be used to hold the container. The sealed sample container should be lowered by hand into the water. At the depth desired for sampling, the lid is removed and the sample container allowed to fill. At all times, the mouth of the container is oriented downstream and the bottom of the container upstream. Sampling on the bottom of a channel may collect some bottom sediment; whereas, skimming a surface sample will allow floating debris to contaminate the sample.

In larger or deeper channels or when sampling from the reservoir, sampling is done using the type of *clean* sampling device previously discussed. The sampling device is lowered to the depth desired, the stopper pulled, and the device allowed to fill before it is removed from the water. The device is then emptied into a clean sample container. This operation is repeated until the container is full. Measurements of flow, depth of sampling, date, and sampling location are noted on the field data form. Each sample bottle must be labeled with the dam name, date, and sample location.

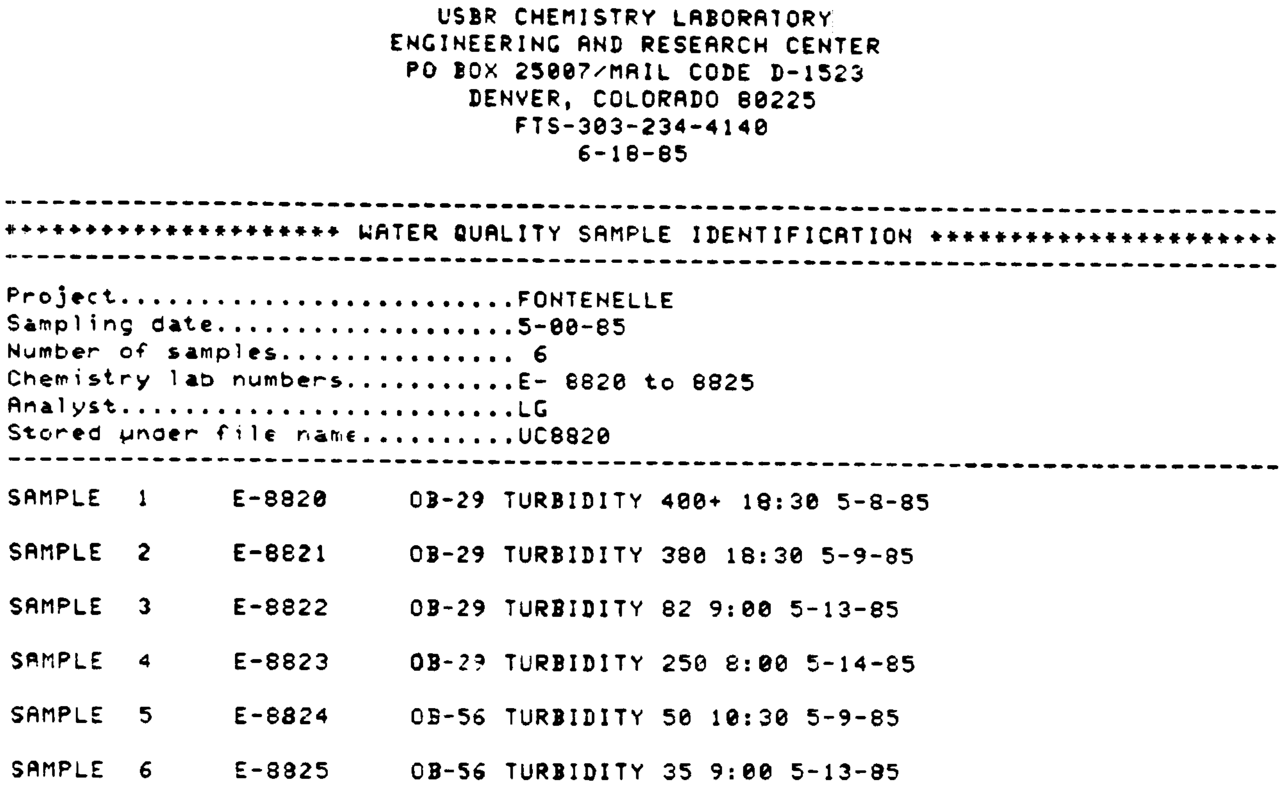
Samples may be temporarily stored in clean, secure areas at temperatures that are not allowed to fall below freezing or to reach high temperatures. The EPA methods manual should be consulted for maximum storage times and allowable temperature ranges for both temporary and longer term sample storage. For some tests, it is recommended that certain additional chemicals be added to the sample to fix certain constituents. Sampling instructions for each dam should state the type of chemicals and amounts to be added to the samples.

c. ***Types of Tests.***—Both field and laboratory testing is normally accomplished for each water testing program. Although most water quality tests could theoretically be performed in the field or in a small field laboratory, it is customary for most tests to be conducted at the E&R Center or in a regional laboratory. Some tests are, of course, preferably accomplished in the field because of their ease of performance or the fear that the values may change over a period of time. Some commonly performed field tests are pH, temperature, conductivity or specific conductance, and occasionally, turbidity.

Laboratory tests commonly performed include pH, conductivity or specific conductance, total dissolved solids, total suspended solids, total cations plus anions, calcium, magnesium, sodium, potassium, carbonate, bicarbonate, sulfate, and chloride. In addition, specialized tests for special site studies are sometimes conducted. Laboratory test reports, such as those shown on figures 7-1 and 7-2, are then prepared and distributed.

d. ***Data Analysis and Presentation.***—Data from the laboratory analysis on seepage water is compared with those from the laboratory analyses on the reservoir water. Thus, it may be determined whether water seeping through the dam, foundation, or abutments is dissolving any material through which it is passing or whether internal erosion is occurring. If the original data is available, it is desirable to compare the seepage water characteristics with the characteristics of the ground water or river water before dam construction, thereby attempting to determine what changes in seepage patterns have been caused by dam construction.

One commonly used method for data presentation is the Stiff diagram [71] shown on figure 7-3. These graphical plots allow changes in water chemistry to be visually confirmed in a quick and direct manner. Computer programs that plot Stiff diagrams are available on the CYBER and Hewlett-Packard computer systems. Stiff diagrams are regularly prepared for illustration of major cation and anion content. Another type of data presentation is shown on figure 7-4.



```
                      USBR CHEMISTRY LABORATORY
                   ENGINEERING AND RESEARCH CENTER
                   PO BOX 25007/MAIL CODE D-1523
                      DENVER, COLORADO 80225
                         FTS-303-234-4140
                             6-18-85

------------------------------------------------------------------------------
******************** WATER QUALITY SAMPLE IDENTIFICATION *********************
------------------------------------------------------------------------------
Project........................FONTENELLE
Sampling date..................5-00-85
Number of samples.............. 6
Chemistry lab numbers..........E- 8820 to 8825
Analyst........................LG
Stored under file name.........UC8820
------------------------------------------------------------------------------

SAMPLE  1     E-8820     OB-29 TURBIDITY 400+ 18:30 5-8-85

SAMPLE  2     E-8821     OB-29 TURBIDITY 380 18:30 5-9-85

SAMPLE  3     E-8822     OB-29 TURBIDITY 82 9:00 5-13-85

SAMPLE  4     E-8823     OB-29 TURBIDITY 250 8:00 5-14-85

SAMPLE  5     E-8824     OB-56 TURBIDITY 50 10:30 5-9-85

SAMPLE  6     E-8825     OB-56 TURBIDITY 35 9:00 5-13-85
```

Figure 7-1. ·Example laboratory test report of water quality analyses.

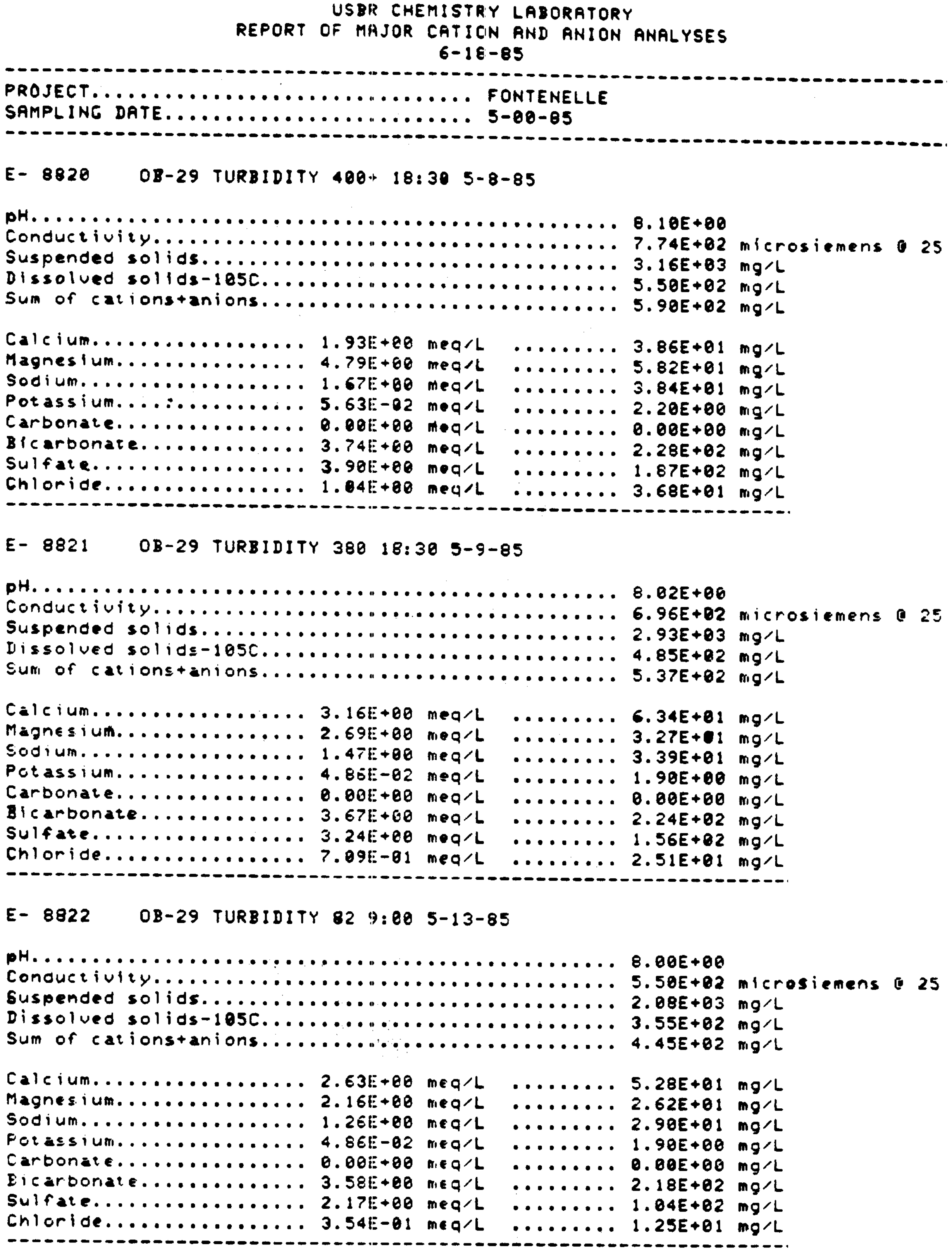
For more complicated data analysis where a number of sources of water must be evaluated and compared, it is recommended that multivariate statistical analysis be used on data sets from a well-designed sampling program. Examples of such analyses are cluster analysis, principal components analysis, and discriminant analysis, which are available on the CYBER system. The Chemistry Laboratory will assist all USBR offices in use of these programs. It is important to note that no amount of graphics or statistical manipulation can correct a poorly designed sampling program or an improper analysis request.

B. Special Devices

65. Automated Devices.—Recent trends in requirements for instrumentation automation at USBR embankment dams have been influenced by the reduction of available trained field forces, by situations requiring very frequent monitoring, by the need for timely data acquisition and analysis, and by the overwhelming volume of data generated by the increasing amounts of instrumentation required at these structures. The amount of data required to be taken manually at some embankment dams can be too excessive for available field personnel to perform along with maintenance and other duties. For these and other reasons, the decision may be made to automate some or all of the instrumentation at a site. (See also app. c).

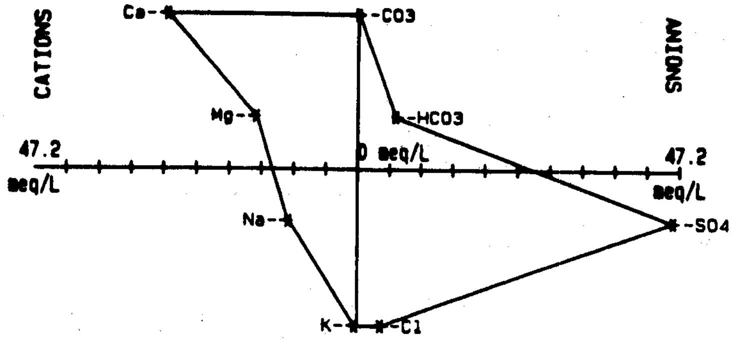
The automation process begins with an economic analysis to determine what automation can be justified on a labor-saved basis. Instruments are then added where they are justified on the basis of dam safety. Next, the instruments or parameters to be read and the accuracy required from each sensor are selected. Several other factors, such as environment, power requirements, interfacing, and where the information gathered is to be used, must also be addressed. In all cases, the parameter to be measured must be transferred into an electrical analog or digital signal so that it can be scaled into engineering units and transmitted, stored, and analyzed.

The following describes some methods of electronically sensing embankment dam structural behavior instrumentation. The electrical signals described are required for remote sensing data acquisition and transmission equipment discussed in the next section.



```
                         USBR CHEMISTRY LABORATORY
                  REPORT OF MAJOR CATION AND ANION ANALYSES
                                  6-18-85
--------------------------------------------------------------------------------
PROJECT................................ FONTENELLE
SAMPLING DATE.......................... 5-00-85
--------------------------------------------------------------------------------

E- 8820    OB-29 TURBIDITY 400+ 18:30 5-8-85

pH.............................................. 8.10E+00
Conductivity.................................... 7.74E+02 microsiemens @ 25
Suspended solids................................ 3.16E+03 mg/L
Dissolved solids-105C........................... 5.50E+02 mg/L
Sum of cations+anions........................... 5.90E+02 mg/L

Calcium............... 1.93E+00 meq/L  ......... 3.86E+01 mg/L
Magnesium............. 4.79E+00 meq/L  ......... 5.82E+01 mg/L
Sodium................ 1.67E+00 meq/L  ......... 3.84E+01 mg/L
Potassium............. 5.63E-02 meq/L  ......... 2.20E+00 mg/L
Carbonate............. 0.00E+00 meq/L  ......... 0.00E+00 mg/L
Bicarbonate........... 3.74E+00 meq/L  ......... 2.28E+02 mg/L
Sulfate............... 3.90E+00 meq/L  ......... 1.87E+02 mg/L
Chloride.............. 1.04E+00 meq/L  ......... 3.68E+01 mg/L
-------------------------------------------------------------------

E- 8821    OB-29 TURBIDITY 380 18:30 5-9-85

pH.............................................. 8.02E+00
Conductivity.................................... 6.96E+02 microsiemens @ 25
Suspended solids................................ 2.93E+03 mg/L
Dissolved solids-105C........................... 4.85E+02 mg/L
Sum of cations+anions........................... 5.37E+02 mg/L

Calcium............... 3.16E+00 meq/L  ......... 6.34E+01 mg/L
Magnesium............. 2.69E+00 meq/L  ......... 3.27E+01 mg/L
Sodium................ 1.47E+00 meq/L  ......... 3.39E+01 mg/L
Potassium............. 4.86E-02 meq/L  ......... 1.90E+00 mg/L
Carbonate............. 0.00E+00 meq/L  ......... 0.00E+00 mg/L
Bicarbonate........... 3.67E+00 meq/L  ......... 2.24E+02 mg/L
Sulfate............... 3.24E+00 meq/L  ......... 1.56E+02 mg/L
Chloride.............. 7.09E-01 meq/L  ......... 2.51E+01 mg/L
-------------------------------------------------------------------

E- 8822    OB-29 TURBIDITY 82 9:00 5-13-85

pH.............................................. 8.00E+00
Conductivity.................................... 5.50E+02 microsiemens @ 25
Suspended solids................................ 2.08E+03 mg/L
Dissolved solids-105C........................... 3.55E+02 mg/L
Sum of cations+anions........................... 4.45E+02 mg/L

Calcium............... 2.63E+00 meq/L  ......... 5.28E+01 mg/L
Magnesium............. 2.16E+00 meq/L  ......... 2.62E+01 mg/L
Sodium................ 1.26E+00 meq/L  ......... 2.90E+01 mg/L
Potassium............. 4.86E-02 meq/L  ......... 1.90E+00 mg/L
Carbonate............. 0.00E+00 meq/L  ......... 0.00E+00 mg/L
Bicarbonate........... 3.58E+00 meq/L  ......... 2.18E+02 mg/L
Sulfate............... 2.17E+00 meq/L  ......... 1.04E+02 mg/L
Chloride.............. 3.54E-01 meq/L  ......... 1.25E+01 mg/L
-------------------------------------------------------------------
```

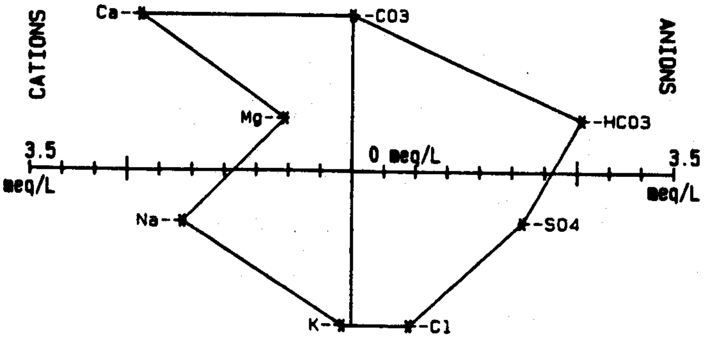
Figure 7-2.—Example laboratory test report of water sample analyses.



Embankment Seepage Point #4

F-1615
04/18/86

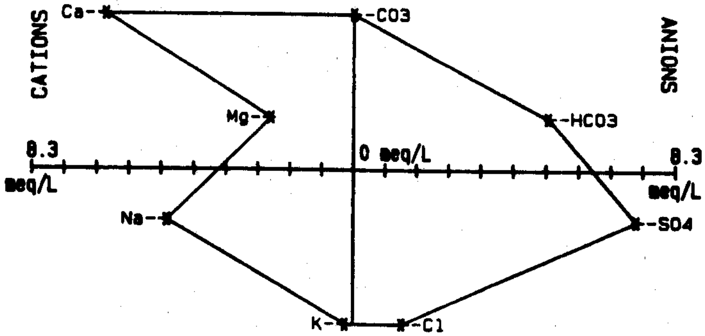
EC (uS/cm)	3530
pH..............	8.03
TDS (mg/L)	3983
TSS (mg/L)	33
Sum (mg/L)	3667



o Grande River 1000' D/S from Elephant Butte Dam

F-1616
04/18/86

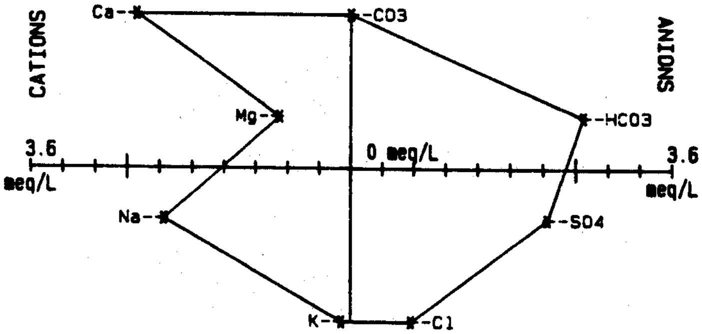
EC (uS/cm)	494
pH..............	8.06
TDS (mg/L)	337
TSS (mg/L)	3
Sum (mg/L)	366



Foundation Relief Well #56N

F-1617
04/18/86

EC (uS/cm)	1149
pH..............	7.83
TDS (mg/L)	867
TSS (mg/L)	
Sum (mg/L)	974



'D' Gallery F-12N

F-1618
04/18/86

EC (uS/cm)	507
pH..............	8.19
TDS (mg/L)	367
TSS (mg/L)	1
Sum (mg/L)	401

Figure 7-3.—Example Stiff diagram of water chemistry data.

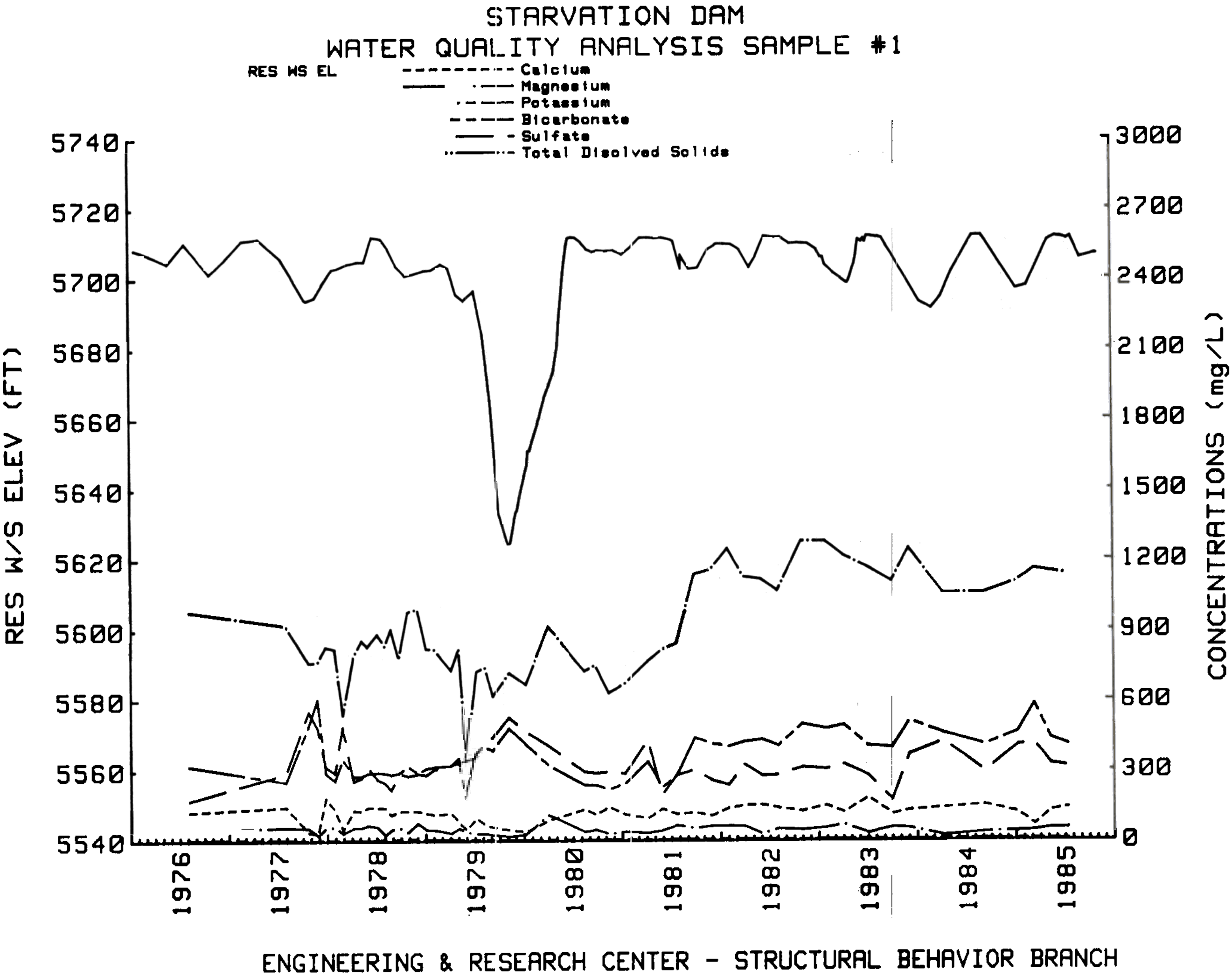


Figure 7-4.—Example plot of water sample chemical concentration data.

a. ***Pressure Measuring Devices.***—Standpipe piezometers and observation wells in the embankment or foundation are good applications for vibrating wire and resistance strain gauge pressure transducers. These sensors are lowered below the water surface to a predetermined elevation. A change in the water surface elevation is reflected as a change in the hydraulic head on the transducer's diaphragm with a corresponding change in the electrical output signal. A miniature piezo-resistive pressure transducer has been developed to fit in a ½-inch-diameter porous-tip piezometer standpipe. Like many low-head pressure transducers, it has a vent tube in the power/signal cable to mechanically subtract atmospheric pressure changes from the pressure head sensed at the diaphragm.

Vibrating-wire pressure transducers are of two varieties: the plucked and the auto-resonating types. The plucked type requires a swept frequency to excite the tensioned wire attached between the diaphragm and the transducer body. A pickup coil then senses the natural frequency of the wire at a particular pressure-induced tension. The auto-resonating sensor has the excitation circuitry housed in the transducer body requiring direct current power. The output is a sinusoidal signal that has a frequency proportional to the sensed pressure.

Transforming the reading of a pneumatic piezometer into an electrical signal requires process control techniques. Normally there are several instruments to be read at the instrument house location. The reading steps require pressurizing the supply line of the piezometer to be read, detecting when the supply gas and the pressure on the piezometer tip are in balance, and then sensing the pressure by an electrical transducer. Desired steady-state flows conditions could be determined by waiting a set time period (say, 5 minutes) or by sensing when pressures stop varying (oscillating) significantly. The supply gas is then depressurized and the next piezometer selected. In some applications, the instruments are kept pressurized at all times; which requires much larger amounts of supply gas, but allows for much higher reading rates than pressurizing each sensor separately.

b. ***Seepage Measuring Devices.***—Seepage is one of the most important parameters measured when analyzing the condition of embankment dams. Using cutoff berms, seepage water is channeled through weirs and flumes. To measure flow through a weir, a transducer is submerged upstream and out of the weir's area of influence. Because a transducer restricts flow through a measuring flume, the transducer is submerged in a stilling well connected to the flume through a pipe. Both types of measuring devices require two equations to compute flow. First, the height of water above the bottom of the weir notch or the floor of the flume is computed from the relationship between the water depth and the voltage output of the transducer. Then the flow is computed using the water height versus flow calibration for the particular device.

c. ***Lake and Tailwater Elevation Devices.***—The difference in head between the lake and tailwater elevations provides the potential for seepage in embankment dams. If there is a previously installed float, tape, and counterweight-driven chart recorder at a dam, the most direct way to automate the readings is by the transfer of the rotation of the drive pulley to a rotary encoder through sprockets and chain. The digital output of the encoder is then transmitted as a scaled value. The advantage of this system is that the scale is controlled by the size of the sprockets and the zero offset can be set through switches on the instrument. Only the offset switches need to be changed to keep the encoder and chart recorder readings equal. The mercury manometer system used at some locations may be automated in a similar manner.

In the absence of chart recording equipment, pressure transducers may be used as discussed previously. However, these transducers are more difficult to maintain in calibration and require the use of special methods to handle the drift and hysteresis characteristics.

The electronics required to measure inflow and outflow from a reservoir parallels techniques used to measure seepage and lake elevation. Extra protection, such as a well house in the stream bank, is required to protect the measuring system from damage due to ice and debris. Existing structure, such as USGS stream gauging stations, already exist on many tributaries.

In general, nearly every type of instrument in use today could be automated to at least some extent. Obviously, economic considerations largely control such efforts.

66. Remote Sensing Devices and Methods.—The advent of less expensive, microprocessor-controlled, data acquisition equipment suitable for the field environment has made automatic data acquisition more attractive for monitoring embankment dams. The development of a broad line of geotechnical sensors, discussed in the previous section, provide electrical signals to be processed by this equipment. The signal processing ranges from hand-held units that scale signals from a few transducers to distributed systems that handle hundreds of sensors and provide satellite and telephone transmission capabilities.

a. ***Automatic Data Acquisition.***—Normally, the use and environment dictate the type of data acquisition equipment selected for a project. Small projects where only a few transducers are read on a daily or weekly basis might only require a hand-held unit with sensor excitation and digitizing capabilities plus a printer for recording the readings. These units can be powered by rechargeable batteries and have sealed housings and keyboards for protection against moisture.

Intermediate systems are usually configured to read 5 to 25 transducers in a local area of interest. They may also contain a printer and tape cassette recorder for data storage. Data on the tape are transferred to a computer for processing. Intermediate data acquisition systems are useful when data must be taken faster than possible with existing personnel, such as for a well drawdown test.

When automating large embankment dams and appurtenant structures, multiunit monitors integrated with a central data collection station are the most advantageous. Because the sensors to be monitored at these dams cover such a wide area, clustering 20 to 50 transducers at one remote monitor that in turn communicates the data to a central processor is more economical than connecting all sensors to a central scanner. Because the operation of a multiunit system is not dependent on one reading station, a failure will not cause total system failure.

Transmission from individual monitors to a central processor is normally performed by a two-wire serial data link cable or radio frequency transmission. The wire link is preferred when the distance to the central station is only a few hundred feet. If the distance is larger or the terrain is difficult, the radio transmission becomes more attractive.

There are several ways of protecting remote data acquisition systems from the environment found at a dam. Where instrument houses are provided, the unit should be placed in an enclosure designed to keep out moisture. If there are no shelters present, below ground enclosures made from plastic pipe or other noncorrosive material can be provided. It is important that these enclosures be tested before installation.

The remote monitors must also be resistant to the electrical environment found at a dam. Although the units are required to detect changes in sensor input of a few thousanths of a volt, they must be protected from lightning strikes and other electrical surges that can produce thousands of volts. Some of the factors that should be considered when reviewing system design are isolation from earth ground, use of transformer coupling, varistors, gas discharge tubes, and battery power for protection.

The remote monitors must be able to handle a multitude of sensor types and conditions. The conditions are common voltage ranges from millivolts to several volts full scale, resistance measurements for potentiometric devices, vibrating-wire excitation and sensing, milliampere detection, and encryption of digital data from rotary encoders. Excitation power strobing should be provided for reading transducers. To be read correctly, some sensors require a warmup delay period after excitation power is applied.

The central processor performs several communications functions. It acts as the system communications controller for setting scan intervals at the remote monitors, setting system polling intervals, receiving out of limit warnings from the remotes, handling remote terminal requests from telephone connections, providing microwave and satellite transmission of blocks of data, and placing warning messages to preprogrammed telephone numbers when parameters are exceeded. The central processor must handle contention problems between different communication elements that require protocol algorithms and setting up priorities.

The data processing performed at the central processor includes collecting data from the remote units, linear and nonlinear scaling into engineering units, setting warning limits to be used for reporting anomalies, performing data smoothing, and displaying histograms plus other statistical data processing. Storage for long-term data retrieval is required to produce time history displays.

b. ***Satellite Transmission.***—An option for transmitting data to the CYBER computer data files at the E&R Center is to use the GOES (Geostationary Operational Environmental Satellite) West satellite. The Division of Atmospheric Resources Research has transmission time intervals for the satellite that are not currently used and are available to other potential users. Satellite transmission generally operates as follows:

(1) Data at a remote location are collected at a transmitter location and transmitted to the GOES satellite using a crossed YAGI antenna. Data are transmitted during set 1-minute transmission periods. Transmission periods can be hourly, or less frequently, depending on the amount of data to be transmitted. Transmissions begin with the "transmitter identification," followed by the data, and then the "sign off" signal is given.

(2) The satellite relays the data to the satellite down-link at the E&R Center. The satellite operates at 110-baud which is, unfortunately, quite slow.

(3) Data are received at the Division of Atmospheric Resources Research satellite down-link and is brought over to the Cyber computer data files.

Reliability of data transmissions via satellite is considered to be very high.

Chapter VIII

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APPENDIX A
SAMPLE SPECIFICATIONS

Appendix A

SAMPLE SPECIFICATIONS

EDI-1, Hydraulic Twin-Tube Piezometer Tip Assembly

(1) Foundation and embankment-type piezometer tip assemblies shall be fabricated and furnished complete with accessory materials in accordance with the details on the plan drawings. The piezometer tip assemblies shall include:

(a) Ceramic filter disks.—The ceramic filter disks shall be equal to Coors Ceramic Type P-3 disks, pore size 1.1 to 2.2 microns, air-entry pressure of 18 to 28 lb/in^2 and 80 to 90 lb/in^2, as manufactured by the Coors Porcelain Company, 600 Ninth Street, Golden, Colorado 80401. The tolerances shall be plus or minus 0.005 inch for the diameter and thickness of disk, except that chips on the edges $^1/_{32}$ inch in maximum size will be allowed.

(b) Alundum filter disks.—The alundum filter disks shall have one of the following porosities: P-2120 fine, average pore size of 60 microns; P-260 medium, average pore size of 164 microns; P-236 coarse, average pore size of 240 microns, as manufactured by the Norton company. The tolerances shall be plus or minus 0.005 inch for the diameter and thickness of disk, except that chips on the edges $^1/_{32}$ inch in the maximum size will be allowed.

(c) Piezometer tip bodies and keeper plates.—The piezometer tip bodies and keeper plates shall be fabricated from polypropylene plastic stock rod having a diameter as shown on the drawings. The material shall be natural and contain no foreign substances. The ¼-inch thick edges of the keeper plates shall be rough buffed to remove any saw marks, and the tolerances for the bored holes shall be $^1/_{32}$ inch. The piezometer tip assemblies shall be equal to those shown on figures 2-8 and 2-10.

(d) "O" rings, for placement around the 1-inch diameter alundum or ceramic disks, shall have approximately 1-inch inside diameter and 1¼-inch outside diameter and shall be equal to Garlock No. 24849-19, Nitrile rubber, as available from Garlock, Inc., 1863 Wazee Street, Denver, Colorado 80202.

The completed piezometer tip assemblies shall be maintained in a saturated condition and shall be protected from freezing until final installation in the field.

(2) Metal screen.—Metal screen for foundation-type piezometer assembly shall be No. -6 mesh bronze or brass wire cloth.

(3) Cloth bags.—Cloth bags shall be 5 by 7 inches with drawstring.

(4) Identification tags.—Indentification tags shall be of durable metal or plastic, suitable for positive identification during field installation, and capable of being tied or loosely clamped to the lengths of $^5/_{16}$-inch outside diameter plastic tubing.

EDI–2, Polypropylene Tubing

Polypropylene tubing shall consist of:

(1) Plastic tubing have $^{5}/_{16}$-inch outside diameter shall be manufactured from a suitable plastic material which shall meet the dimensional and average physical properties described below. The plastic material used for extrusion of the tubing shall be homogeneous, virgin plastic, and shall contain no foreign substances other than an insert coloring agent.

Dimensional tolerances.—Tubing shall be conditioned for 24 hours at 73 °F and 50 percent relative humidity. Average of six readings taken at different locations on specimens shall meet the following:

Mean outside diameter. ·0.315 inch, plus 0.005 inch minus 0.010 inch.

Wall thickness.—0.060 inch, plus 0.005 inch, minus 0.005 inch. Cut section of tubing open lengthwise; use pointedhead micrometer to reduce effect of curvature of tubing on measurements.

Physical properties.—Average of three specimens: Tests shall be conducted in accordance with ASTM Designations, where referred to below, except that where there is a conflict between the requirements of this paragraph and the requirements of the ASTM Designations, the requirements of this paragraph shall govern.

Hardness, Rockwell. ·R-85 to R-110 ASTM Designation: D 785.

Water absorption.—0.02 percent after 24 hours immersion, maximum. Scrub specimens clean with water and cleaner, condition at 50 °C plus or minus 3 °C for 24 hours. Wipe and blow dry after immersion. Specimens shall be 5 inches long. ASTM Designation: D 570.

Boiling water.—Place specimens in pan of boiling distilled water for 5 minutes. Inspect for deterioration and whitening. Use same specimens for rupture strength test as described below. Specimens shall be 12 inches long.

Specific gravity.—0.92 maximum. ASTM Designation: D 792.

Cold bend.—Without collapse or rupture, withstand a 360° bend around a 2-inch diameter mandrel. Condition specimens and mandrel for 3 hours at 25 °F and conduct test at 25 °F. Bend tubing against the curve of the coil. Use same specimens for rupture strength test as described below. Specimens shall be 12 inches long.

Rupture strength.—The rupture strength shall be determined for virgin specimens, boiling water specimens, and cold bend specimens as prescribed below and in ASTM Designation: D 1599. Tests shall be conducted in air at 73 °F. Specimens shall be loaded from zero to bursting in 60 to 75 seconds.

Virgin specimens.—1,400 lb/in^{2}, minimum, ultimate rupture strength. Specimens conditioned 24 hours, in air, at 73 °F, percent relative humidity.

Boiled specimens.—80 percent minimum of ultimate rupture strength of a virgin specimen. Specimens shall be cooled normally, in air, to 73 °F.

Cold bend specimens.—90 percent minimum of ultimate rupture strength of a virgin specimen. Specimens shall be warmed normally, in air, to 73 °F.

Color.—Light yellow semiopaque tubing is desired but is not required. A sample of the colored tubing shall be submitted for approval prior to extrusion.

Polypropylene plastic material from selected formulations extruded as tubing has been found to meet the specifications described above.

The tubing shall be equal to the Parflex polypropylene plastic tubing manufactured by Parker Hannifin Company, 30240 Lakeland Boulevard, Wickliffe, Ohio 44092.

The ends of each coil of tubing shall be crimped or sealed prior to shipment. Tubing shall be shipped in 30-inch minimum diameter coils or spools, having a minimum of 2,000 feet of tubing per coil. The lengths in each coil of tubing shall be marked and tagged.

(2) Natural tubing.—Natural or uncolored plastic tubing having ⅜-inch outside diameter (plus 0.005 inch), minus 0.010 inch and a 1/16-inch wall thickness shall be supplied of polypropylene plastic material equal to that extruded for the requirements in above paragraphs. The tubing shall be supplied in a 100-foot coil.

EDI-3, Hydraulic Twin-Tube Piezometer Terminal Well Equipment

The terminal well equipment shall consist of:

(1) Air trap.—The plastic air trap shall be fabricated as shown equal to that fabricated by the Denver Machine Shop, Inc., 1421 Blake Street, Denver, Colorado 80202, and fabricated to the requirements shown on the drawing EDI-3.

(2) Water filter.—The water filter unit shall be of the cartridge type, equal to Fram model No. 243237, Fram Corporation, Pawtucket Avenue, Providence, Rhode Island 02916, complete with cartridge equal to Fram model No. PR3383.

(3) Plug shutoff valves.—Plug valves, brass, having ¼-inch female standard pipe connections shall be equal to Circle Seal Products Company, valve No. 9559B-2PP as available from Klein Aerospace Engineering Sales Company, PO Box 1056, Englewood, Colorado 80110, or from the manufactuer, Circle Seal Products Company, Inc. PO Box 3666, Anaheim, California 92803.

(4) Check valves.—A check valve, brass, having ¼-inch female standard pipe connections shall be equal to Circle Seal, valve No. 259B-2PP as available from Klein Aerospace Engineering Sales Company.

(5) Relief valves.—The relief valves, brass, having one ¼-inch female and one ¼-inch male standard pipe connections shall be equal to Circle Seal, series No. 559B-2MP as available from Klein Aerospace Engineering Sales Company. The valves shall restrict pressures in excess of a limit of the pressure gauge.

(6) Teflon tape.—Teflon tape, furnished in rolls ½ inch wide by 24 feet long, equal to Teptape, shall be used when assembling standard pipefittings in the piezometer manifold system. Shears must be used to cut the tape from the rolls or dispensers, and only a single wrapping of tape shall be used on the pipe threads.

(7) Blower fan unit.—The blower fan unit shall have a direct-connected motor and a standard steel wheel, which will produce 423.7 ft^3/min, at 0.2-inch static pressure and 459 ft^3/min at 0.1-inch static pressure. The motor shall be ⅙ horsepower 115 volts, single phase, 60 hertz, and run at from 1,700- to 1,800-r/min synchronous speed. The unit shall be equal to American Blower Utility Set, catalog No. S60-HJ, or Buffalo Forge company, No. C, having a CW-Baud (45 above BHD rotation and discharge) and a KH-48 frame and mount.

A motor-starting switch for separate surface mounting and for controlling operation of the motor shall be supplied. The starting switch shall be a manual Type 2 pole suitable for operation with the motor described above and shall be contained in NEMA Type 4, watertight enclosure, having threaded conduit entrance or entrance suitable for connection to rigid steel conduit. Switch shall provide motor thermal overload protection, and the overload device shall be set to trip between 115 and 120 percent of the rated normal full-load running current of the fan motor. Switch shall have an externally operable toggle or lever-style operating handle and handle positions marked ON and OFF.

(8) Pump, electric.—The electric pump shall be furnished complete with frame, baseplate, and electric motor and shall be equal to Liquiflo model No. 32FS 1333S available from BF Sales Engineering, Inc. PO Box 1108, Arvada, Colorado 80001, or from the manufacturer, Liquiflo Equipment Company, 140 Mount Bethel Road, Warren, New Jersey 07060.

(9) Brass pipe and fittings.- Brass pipe and pipe fittings shall be ¼-inch standard brass pipe.

(10) Hydraulic test pump.—Hydraulic test pump shall be hand operated, having a 150-lb/in^2 working range and equal to Deming Pump No. 594, as available from Hendrie and Bolthoff, 550 West 53rd Place, Arvada, Colorado 80001, or from the manufacturer, Deming Division, Crane Company, 42 Broadway, Salem, Ohio 44460.

(11) Master gauge.—Compound gauge, Weiss Special No. WEI634231, 6-inch dial size, having a phenol case with flanged mounting, calibrated in feet of water (or meters of head) on both vacuum and pressure sides. The vacuum capacity shall be 34.5 feet of water with positive pressure capacity of 231 feet of water and graduated throughout both dial ranges in 1-foot increments. The gauge shall be equipped with a plastic face, ¼-NPT top connection, phosphor bronze Bourdon tube, and with a stainless steel or bronze movement. It shall be accurate to within 1 percent over the full range of dial graduations. Prior to shipment, the gauge shall be tested for 1 percent accuracy at readings of -10, 0, 100, and 200 feet with a written certification provided accordingly. Available from McCoy Sale Corporation, 2190 West Bates Avenue, Englewood, Colorado 80110.

(12) Separate gauges.—Bourdon tube, compound, altitude, gauge, having a phenol case with flanged mounting, calibrated in feet of water on both vacuum and pressure side. Dial size shall be 4-inch size with an adjustable pointer and graduated for each 2 feet of head, both on the vacuum and pressure sides. The vacuum capacity shall be 34.5 feet of water with positive pressure capacity of 231 feet of water. The gauge shall be equipped with a ¼-inch NPT brass top connection, a phosphor bronze Bourdon tube, and an acetal copolymer movement with no ferrous parts. The calibrations on both the vacuum and pressure sides shall be in feet of water. The gauge shall have an accuracy of 3:2:3. Prior to shipment, the supplier shall check each gauge at readings of -10, 0, 100, and 200 feet of pressure. The gauge shall be equal to Dobbie Instruments model No. PG100428. Available from Rocky Mountain Export Company, Inc., 1860 Lincoln Street, Denver, Colorado 80295.

EDI-4, Backfill Materials for Piezometer Installation

Backfill materials for piezometer installation shall consist of the following:

(1) Graded sand.—Graded sand for backfill in the instrument influence zone shall be a washed sand with 95 percent of its total gradation falling between U.S. Standard sieve sizes No. 8 and No. 50. No more than 2 percent shall pass a No. 200 screen and no portion of the backfill shall be retained on a No. 4 screen.

(2) Bentonite.—All bentonite used shall have a minimum purity of 90 percent montmorillonite clay and a moisture content of no more than 10 percent as packaged. The bentonite pellets shall have a ½-inch diameter and a minimum dry bulk density of 82 lb/ft^3. In cases that require

bentonite to be mixed with other materials, a powdered or granular bentonite shall be used with a minimum dry bulk density of 54 lb/ft^3. Bentonite products shall be equal to those provided by American Colloid Company, Water Well Products Division, 5100 Suffield Court, Skokie, Illinois 60077.

(3) Bentonite/concrete sand.—Bentonite/concrete sand shall be a 1:3 mixture of a fine-grained powdered or granular bentonite and sand by dry weight. A dry bulk density of 54 lb/ft^3 for powdered bentonite shall be used when calculating mix volumes. Mixtures may be proportioned by either volumetric or gravimetric methods.

EDI–5, Pneumatic Piezometer Tip Assembly

A pneumatic piezometer consists of a pneumatic pressure transducer covered with a porous stone. The pneumatic piezometer shall be capable of continuously monitoring fluid pressure as it acts upon a nonmetallic flexible diaphragm having negligible spring force with excess pressure vented directly to the atmosphere through an opened valve and vent tube, thus requiring a flow to be maintained through the transducer and to atmosphere through the vent tube while readings are being taken. This transducer style is commonly called the null-balance design. The transducer shall not require in-place calibration and shall have negligible zero shifts or changes in sensitivity. Calibration curves or transducer-induced spring-load factors shall not be necessary to take the readings or reduce the instrument's data. The pneumatic piezometer transducer shall be capable of accurately measuring pore pressures ranging from 2 to 200 lb/in^2. A 3-inch length of porous tube with an inside diameter of approximately 1 inch and ¼-inch minimum wall thickness shall be attached to the piezometer tip with a suitable epoxy adhesive as shown on the drawings. The dimensions of the porous tube may vary slightly, but in no case shall the tube's effective filtering area be less than 7 in^2 as shown on figure EDI–5. Each piezometer shall also be fitted with a sintered stainless steel filter between the porous-tube cavity and the piezometer diaphragm.

Porous stones for pneumatic piezometers located in zone 1 material shall have saturated bubbling pressures of 18 to 28 lb/in^2 and shall be saturated by the transducer manufacturer and shipped to the construction site in water-filled containers. Porous stones for all other pneumatic piezometers shall have a nominal pore size of 60 microns.

Piezometers with 60-micron pore size stones shall not be saturated prior to shipment by the manufacturer but shall be provided with containers to place piezometer tips in water once they arrive on the site. The pneumatic piezometer transducers shall be as manufactured by Slope Indicator Company, 3668 Albion Place North, Seattle, Washington 98103, model No. 514178, or equal.

EDI–6, Tubing Bundles

Pneumatic tubing bundles shall be as follows:

The connecting air leads from the tube bundle terminal assemblies as provided below, to pneumatic piezometers, settlement sensors, and total pressure cells shall be a polyethylene tubing constructed of a DuPont Alathon 2020, having a minimum water absorption of 0.015 percent, and a minimum burst pressure of 900 lb/in^2. For the purpose of tube identification, the tubes within a bundle shall be different colors as recommended by the instrument manufacturer. The tubes shall be a $^3/_{16}$-inch outside diameter, and the tube bundle shall be covered by a polyethylene continuous sheath. No splices or connections will be permitted in the polyethylene sheath or polyethylene tubes between the pneumatic piezometer, pneumatic settlement sensor, or pneumatic total pressure cell, and the tube bundle terminal assemblies.

The individual tube bundles will be cut to the length required and attached to the pneumatic piezometer, settlement sensors, or total pressure cell by the manufacturer. All tubes with instruments attached shall be placed on reels. Lengths required will include the length to the instrument in the drill hole where applicable, the length needed in trenches, length to instrument houses, an additional 10 percent for slack, and an additional 10 feet per instrument. The manufacturer will attach tube bundle terminal assemblies and dust caps and ship piezometers, total pressure cells, settlement sensors, tube bundles, and terminal assemblies to the field as a unit.

Tube bundle marking.—All tube bundles shall be permanently marked with the number of the piezometer, settlement sensor, or total pressure cell to which they are attached. This marking shall be every 10 feet over the length of the tube bundle and shall be carried out by the instrument manufacturer prior to shipment to the construction site.

Hydraulic tube bundle.—The connecting hydraulic tubing from the pneumatic settlement sensor to the hydraulic reservoir shall be polypropylene tubing constructed of a stabilized polypropylene plastic having an air absorption of 0.02 percent and a minimum burst pressure of 500 lb/in^2. For the purpose of tube identification, the tubes within a bundle shall be of different colors as recommended by the instrument manufacturer. The tubes shall be ¼-inch outside diameter and the tube bundle shall be covered by a polyethylene continuous sheath. No splices or connections will be permitted in the polyethylene sheath or polypropylene tubes between the pneumatic settlement sensor and the hydraulic reservoir.

The individual hydraulic tube bundles will be cut to the length required and attached to the pneumatic settlement sensor by the manufacturer. Lengths required will include the length needed in drill holes and trenches, length to terminal well on the downstream face of the dam, or to the instrument house at the top of the dam, additional 10 percent for slack, and an extra 10 feet per unit. The manufacturer shall provide plugged connectors on the liquid-filled hydraulic tube bundles, and these connectors shall be compatible with the reservoir to which the hydraulic tube bundle is to be attached with no other connectors required. The manufacturer will ship each respective instrument and its closed-end tube bundle to the field as a unit.

EDI–7, Tubing Bundle Terminal Assembly

For the purpose of terminating the individual input and output tubes of the pneumatic tube bundle, a 60-micron inline filter with replaceable filter element, hex nipple, and a plug coupling shall be attached as shown on the drawings. The 60-micron inline filter shall have ¼-inch N.P.T. female threads and shall be a Nupro B--4F4–60 as manufactured by the Nupro Company, 4800 East 345th Street, Willoughby, Ohio 44094, or equal. The plug coupling shall be the model No. B2–K16 as manufactured by the Hansen Manufacturing Company, 4050 West 150th Street, Cleveland, Ohio 44135, or equal. Two Hansen metal plug protector caps, model No. PDC-2HK, shall be furnished for each plug coupling. The filter and plug coupling shall be joined together by a ¼-inch male hex nipple No. B–4–HN as manufactured by the Cajon Company, 32550 Old South Miles Road, Cleveland, Ohio, 44139, or equal. All vent tubes shll be provided with inline filters but no plug connectors or caps. For details see figure EDI–7.

EDI–8, Portable Pneumatic Pressure Indicator (Gauge Box)

The gauge box shall be a self-contained unit capable of being connected to the tube bundle terminal assemblies by use of connecting leads as provided below. The gauge box shall have a self-contained gas supply bottle that can be charged from a separate supply cylinder. The pneumatic instrument input circuit of the gauge box shall have internal gas pressure regulation limiting gas pressures downstream of the self-contained supply to 300 lb/in^2 and manual pressure regulation ranging from 0 to 300 lb/in^2. Gauges with 2-inch dial faces, reading in units of pounds per square inch, shall be provided that indicate pressure in the self-contained gas supply bottle and gas pressure in the pneumatic instrument input circuit downstream of the positive cutoff valve. The main test gauge for determining pneumatic instrument pressures shall have a 6-inch dial face, mirror parallax control, automatic temperature compensation, and manual zero control. A gauge accuracy of 0.1

percent and sensitivity of 0.01 percent are required over the gauge's full 300-lb/in^2 range. Reading increments shall be in 1-lb/in^2 units.

A valve shall be provided to allow positive cutoff of all gas flow downstream of the manual regulator. The gauge box shall contain a gas flow control to limit the volume of gas and a flowmeter indicating volume of gas flow used while pneumatic instrument data are being taken. The gauge box shall be provided with a direct-flow circuit bypassing the flow control to expedite filling of long tube handles. A means of bleeding gas pressure from the pneumatic instrument input circuit downstream of the positive cutoff valve shall be provided.

All valves with manual controls that are used for switching, bleeding, or positive cutoff shall be ball valves. Toggle-type valves will not be allowed in the gauge box.

The self-contained gas supply shall be fitted with a Hansen model No. 1-K11 steel plug coupling for filling from an external supply cylinder.

Between the self-contained supply tank and the plug coupling for filling the tank, there shall be a suitable check valve to keep gas from bleeding back to the plug coupling.

The coupling for the pneumatic instrument input and for a return line, if required, shall be a Hanson model No. B2–H16 socket. Two metal dust caps with chains for each plug shall be provided. All gauges, valves, and couplings shall be marked to indicate function on/off/bleed, handle positions, or gas flow direction. Markings shall be plastic and attached to the gauge box panel with a suitable epoxy adhesive. "Dymo"-type marking tape is not acceptable.

The gauge box shall be model No. 51411–A AFC as manufactured by the Slope Indicator Company, 3668 Albion Place North, Seattle, Washington 98103, or model No. C–102–3, or equal.

Connecting Leads.—Leads used to connect the gauge box to the tube bundle terminal assemblies shall be 15 feet in length. If a single lead is required, it shall be black in color; if two leads are required, the instrument input lead shall be black and the return lead shall be natural color, and they shall be covered with a continuous polyethylene sheath. In all cases, the leads shall be of the same diameter as the tube bundle material. All leads shall be of Nylon II as manufactured by Gould Imperial-Eastman, 6300 West Howard Street, Chicago, Illinois 60648, type SN, or equal. Each lead shall be provided with a Hansen model No. B2–H16 socket coupling on both ends that is compatible with the plug couplings on the gauge box and on the tube bundle terminal assemblies. Two Hansen model No. SDC–2–HK metal dust caps shall be provided for each socket coupling. One dozen extra O rings of the proper size per socket and six sets consisting of a Hansen model No. B2–H16 socket with an SDC–2–SK metal dust cap and B2–K16 plug with a PDC–2–HK metal dust cap shall be required. Hansen couplings, plugs, and dust caps are manufactured by the Hansen Manufacturing Company, 4050 West 150th Street, Cleveland, Ohio 44135.

The Government shall require an additional 100 feet of connecting lead. This lead material shall be furnished without couplings and shall conform to the specifications for connecting leads as stated in this paragraph in all other manners. This 100 feet of lead material shall be furnished on a separate roll with the ends taped to protect against entry of foreign material.

Self-contained gas supply bottle filling lead.—A 5-foot-long, high-pressure lead fitted with a Hansen 1–H11 steel socket coupling on one end and a fitting on the other end that will fit the Government's external nitrogen supply cylinder shall be provided by the Contractor. The Government shall require two Hansen SDC–1–HK metal dust caps. Hansen couplings and dust caps shall be manufactured by the Hansen Manufacturing Company as previously stated.

EDI-9, Pneumatic Terminal Panel

The pneumatic terminal panel consists of a metal, enclosed, stationary system including two control manifolds and one vent manifold that shall be securely anchored to the floor of the instrument house. The terminal panel's manifolds shall be constructed so as to allow the operator to collect data from pneumatic instruments. The terminal panel shall be furnished with a gas supply lead which allows the attachment of a gas supply tank, and permanently mounted in the terminal panel shall be a gauge indicating gas supply tank pressure. Directly downstream of the gas supply tank pressure gauge shall be a primary gas pressure regulator that steps the supply tank pressure down to a maximum of 300 lb/in^2. The primary regulator shall not be accessible to the operator without first removing the terminal panel's face. A relief valve shall be located immediately downstream of the primary regulator limiting pressure below that point to a maximum of 325 lb/in^2. A secondary regulator, directly downstream of the relief valve, shall allow the operator to select any pneumatic supply pressure from 0 to 300 lb/in^2. The pneumatic instrument circuit downstream of the regulator shall consist of an automatic flow control and flowmeter (pneumatic instrument input leg), a bypass leg that facilitates the filling of long lines, and downstream of the point that the bypass leg reenters the pneumatic instrument input leg, a piezometer input manifold as described below. A 3-way ball valve shall be provided to allow the operator to choose either the bypass leg, the pneumatic instrument input leg, or to cut off the circuit.

The pneumatic piezometer or settlement sensor input manifolds shall have a separate portal for each instrument input which shall be equipped with a ball valve to allow the operator to choose the instrument to be read by cutting off all other instruments.

At the base of each instrument input manifold, there shall be a Hansen B2–16K plug which may be isolated from the rest of the manifold with an on-off valve. If additional manifolds are required for instrument output lines, they shall have Hansen B2–16K plugs and all other valves required for the input manifolds. The main test gauge for the pneumatic piezometer circuit shall have a 6-inch dial face, mirror parallax control, automatic temperature compensation, and manual zero control. A gauge accuracy of 0.1 percent and sensitivity of 0.01 percent are required over the gauge's full 300-lb/in^2, double-rotation dial range. Reading increments shall be in 1-lb/in^2 units. Between the manifold select valve and the pneumatic piezometer test gauge, a 300-lb/in^2 relief valve shall be placed to protect the gauge.

The main test gauge for the pneumatic settlement sensor circuit shall be a 6-inch dial face, double-rotation gauge with automatic temperature compensation and a manual zero control. The gauge shall have an accuracy of plus or minus 0.1 percent over the gauge's full 60-lb/in^2 range with a repeatability of plus or minus 0.03 percent and a sensitivity of plus or minus 0.01 percent full scale. Reading increments shall be in 1-lb/in^2 units. Between the manifold selector valve and the pneumatic settlement sensor test gauge, a 55-lb/in^2 relief valve shall be placed to protect the test gauge.

The pneumatic system vent manifold shall accept vent lines from all pneumatic instruments. At the top of the vent manifold, there shall be a 60-micron filter to prevent material from entering the vent manifold.

All valves used in the pneumatic terminal panel shall be ¼-inch Teflon seated ball valves. No toggle valves will be permitted in the system.

The pneumatic terminal panel shall be sized in such a manner as to allow it to be removed from the instrument house, through the doorway, without being disassembled.

The pneumatic terminal panel shall be as manufactured by the Slope Indicator Company, 3668 Albion Place North, Seattle, Washington 98103, model No. 514151, or equal.

EDI-10, Pneumatic Terminal Pipe

The pneumatic terminal pipe shall be a standard, schedule 40, 6-inch diameter, galvanized iron pipe with a terminal pipe panel face attached vertically to the inside in such a manner that no less than 20 pneumatic instruments can be terminated at the pipe.

An overlapping lockable, machined cap shall be provided with each pipe. The overall dimensions may vary slightly but in no case shall the terminal be less than 3 feet or greater than 5 feet above the ground. All terminals within the terminal pipe shall be Hansen B2-16H socket connectors. The terminal pipe shall be as manufactured by Slope Indicator Company, 3668 Albion Place North, Seattle, Washington 98103, model No. 514171, or equal.

EDI-11, Riser Pipes, Plugs, and Fittings

Riser pipes.—The riser pipes shall consist of a minimum 18-inch outside diameter schedule 20 steel pipe, a minimum of 6 feet long. A 1-inch wide slot shall be cut into the pipe from the top to the bottom for tube bundle entry. A steel plug shall be used to seal the slot in the riser during compaction.

Riser plugs.—The riser plugs shall be fabricated from steel and force fitted or tack welded into the 1-inch slot cut in the riser pipe for full length as shown on the drawings.

Line fittings.—All flareless fittings used in the gauge box, pneumatic terminal pipes, pneumatic terminal panel, tube bundle terminal assemblies, connecting leads between gauge box and tube bundle terminal assemblies, reservoirs, and all other portions of the pneumatic instrument installations shall be brass Swagelok type as manufactured by the Crawford Fitting Company, 29500 Solon Road, Solon, Ohio 44139, or Parker CPI fittings as manufactured by the Parker Hannifin Company, 17325 Euclid Avenue, Cleveland, Ohio 44112.

The Government shall require an additional 100 brass front and back ferrules in each size used for the tubes of the tube bundle and 100 brass nuts for each tube size of the extra ferrules. If the size of any tube in the gauge box is not that of the tubing of the tube bundle, 100 additional front and back ferrules and 25 additional nuts shall be furnished to the Government in each size used, except that of the tube bundle. Three hundred additional brass fittings with ¼-inch male N.P.T. threads (model No. B-300-1-2) on one end and flareless tube fittings of the size of the tubing of each tube bundle on the other end with ferrules and nuts shall be furnished to the Government.

EDI-12, Vibrating-Wire Piezometer and Cable

Vibrating-wire piezometer.—A vibrating-wire piezometer consists of a transducer capable of transforming a piezometric pressure into resonant frequencies which can be transmitted and displayed. The piezometer shall have an average accuracy of 0.50 percent over its entire range of 0 to 250 lb/in^2 with a resolution of 0.1 percent of full scale. The size of the transducer shall not exceed 0.75 inch in diameter by 4.875 inches in length. Calibration data must be provided with each instrument. The transducer shall be capable of operation in temperatures from −20 to 140 °F and have a thermal constant of 2 minutes per degree of Celsius. The transducer shall have an overpressurization capability of 200 percent. Each piezometer shall be provided with a 50-micron sintered stainless steel filter. All materials shall be stainless steel except the vibrating wire. The interior shall be hermetically sealed to provide a stable, inert atmosphere around the wire to ensure long life of the gauge. Each piezometer shall be equipped with a thermistor with a range of −50 to 60 °C with an accuracy of ±1 °C and a thermal shift corrected to 0.002 percent full scale per degree Fahrenheit. Vibrating-wire piezometers shall be as manufactured by Geokon, 7 Central Ave., Lebanon, New Hampshire 03784, model No. 45005, or equal.

Electrical cable.—Each vibrating-wire piezometer shall be furnished with enough electrical cable for its required length in the trenches, length to the terminal pipe, an additional 10 percent for slack, and an additional 10 feet per instrument. Each cable shall be four-conductor solid round wire of commercially pure annealed copper. Conductor shall meet the requirements of ASTM Designation: B3–69. Wire gauge shall be 22 gauge as specified by American Wire Gauge. The conductors shall be installed with colored insulating-grade high-density polyethylene. All conductors in any single length of wire shall be insulated with the same type of material. The conductor insulations shall be colored with one wire being orange and the other blue.

The cable shall be filled with a filling compound that shall be homogeneous and uniformly mixed; the compound shall be color-less, free from dirt, metallic particles, or other foreign matter, easily removable, be nontoxic, and present no dermal hazards. The filling compounds shall exhibit the following dielectric properties: dissipation factor shall not exceed 0.0015 at a frequency of 1 MHz, volume resistivity shall be not less than 10^{12} ohm/cm, dielectric constant shall not exceed 2.30. The conductors and filling shall be covered by a sheath that consists of an inner jacket of polyethylene, a shield, and an outer jacket of polyethylene. The nominal inner jacket thickness shall be 0.025 inch. The nominal outer jacket thickness shall be 0.030 inch. The inner jacket be applied over the completed core with sufficient filling compound so that void and airspaces do not exist. The jacket shall be free of holes, splits, blisters, or other imperfections.

The outer jacket shall consist of black polyethylene applied over the metallic shield. The outer jacket shall provide a tough, flexible, and durable protective covering, able to withstand exposure to sunlight and stresses expected in normal installation and service within an embankment. Each cable shall be attached to the appropriate piezometer or total pressure cell and permanently marked with the number of the instrument to which it is attached. This marking shall be every 10 feet over the length of the cable and shall be carried out by the instrument manufacturer prior to shipment to the construction site. Each cable shall be mounted on a reel and mechanically protected to prevent damage during shipping. Each reel shall be stenciled or labeled with the name of the instrument, and all wire ends shall be capped on the open end of the wire on the reel. All end caps must be acceptable to the Contracting Officer. The electrical cables shall be equal to those cables manufactured from medium density jacketing material for filled buried wire manufactured for the Rural Electrification Administration REA specification PE–54, dated July 1974. The electrical cable shall be as manufactured by Brand-Rex Company, PO Box 498, Willimantic, CT 06226, part BWF–2P22–127FB, or equal.

Splices.—Splice kits shall be provided to join the electrical cables together as the piezometer cables are removed from risers and to repair damaged cables. These kits shall be water-proof, epoxy resin filled, and include solderless crimps. Crimps shall be Voltrex No. CCS-TV-1818 as manufactured by SPC Technology, PO Box 66175, Chicago IL 60666. A splice kit shall be provided for each piezometer. The kits shall be 3M Scotch Mining and Manufacturing Electro-Products Division, St. Paul, MN 55101, or equal.

EDI–13, Vibrating-Wire Readout Device

The Contractor shall provide a readout unit capable of accepting a signal from a single vibrating-wire piezometer and displaying the frequency reading digitally. The vibrating-wire readout unit shall be as manufactured by Geokon, 7 Central Ave., Lebanon, New Hampshire 03784, model No. GK-401. A battery charger that is capable of recharging the unit's battery from a 110-volt, alternating-current source shall be provided. One dozen short leads capable of attaching to the connectors on the piezometer electrical cable will be provided by the Contractor for connecting the readout unit to the leads on the vibrating-wire piezometers.

Terminal panel.—The terminal panel shall be manufactured to attach no less than 12 vibrating-wire piezometers. Terminal panel shall have a rotary switch which changes the channel of instrument being read. The terminal panel shall be as manufactured by Geokon, 7 Central Ave., Lebanon, New Hampshire, model No. 4000–12B or equal.

EDI–14, Drill-Hole Procedures

Revisions to the preferred procedures for drilling holes in embankments and foundations have not been finalized at the time of preparation of this manual. For interim information concerning currently suggested procedures for drilling requirements for the following types of installations, contact the Division of Geology, E&R Center, Denver, Colorado:

(a) Pneumatic instrumentation installations

(b) Porous-tube piezometer installations

(c) Slotted-pipe piezometer installations

(d) Inclinometer installations

(e) Vibrating-wire installations

EDI-15, Pressure Cells

Pneumatic pressure cell,—A pneumatic pressure cell (see fig. EDI-15) consists of a pneumatic pressure transducer attached to two 9-inch-diameter stainless steel plates welded together at the outer circumference and filled with deaerated oil. The pneumatic pressure cell shall be capable of monitoring static total pressure acting upon a nometallic flexible diaphragm having negligible spring force. In the pneumatic balancing circuit, excess pressure shall be vented directly to the atmosphere through an opened valve and vent tube (tubing described in EDI-6), thus requiring a flow to be maintained through the transducer and to atmosphere through the vent tube while readings are being taken. This transducer style is commonly called the null-balance design. The transducer shall not require in-place calibration but shall have negligible zero shifts or changes in sensitivity. Calibration curves or transducer-induced spring-load factors shall not be necessary to take the reading or reduce the instrument's data. The pneumatic total pressure cell shall be capable of accurately measuring earth pressures ranging from 2 to 300 lb/in^2. The reactive surface shall be clearly marked. The pneumatic total pressure cell shall be as manufactured by Slope Indicator Company, 3668 Albion Place North, Seattle, Washington 98103, model No. 51482, or equal.

Vibrating-wire total pressure cell.—A vibrating-wire total pressure cell consists of a vibrating-wire pressure transducer attached to two 9-inch diameter stainless steel plates welded together at the outer circumference and filled with deaerated oil. The transducer monitors static total pressure acting upon a diaphragm which is attached to the vibrating wire which transforms the pressure into resonant frequencies which can be transmitted and displayed (cable is described in EDI-12). The cell shall have an accuracy of plus or minus 0.5 percent of full scale over its 0 to 100-lb/in^2 range with a resolution of 0.1 percent of full scale. The reactive surface shall be clearly marked. Calibration data must be provided with each instrument. Vibrating-wire total pressure cells shall be manufactured by Geokon, 7 Central Avenue, Lebanon, New Hampshire 03784, model No. 4800E or equal.

EDI-16, Porous-Tube Piezometer Assembly

Porous-tube piezometer.—A porous-tube piezometer shall consist of the following: porous tube, male adapter, pipe plug, and shall be assembled by the use of a two-part epoxy and liquid weld cement.

Porous tube.—Porous tube shall be made of a fine-grain alundum, having a 1-½-inch outside diameter, ¼-inch wall thickness, 24-inch length, with a porosity equal to Norton mix P-2120. The porous tube shall be a No. K-652-1 as supplied by Soiltest, Inc., 2205 Lee Street, Evanston, Illinois 60202, or equal.

Male adapter.—Male adapter shall be a ¾- by ¾-inch schedule 40 PVC male adapter, glued with a two-part epoxy in the top of the porous tube. The adapter shall be a male 013-0075 as supplied by Reeves Plastic Pipe, 4295 Kearney Street, Denver, Colorado 80216, or equal.

Pipe plug.—Pipe plug shall be a ¾-inch schedule 40 PVC pipe plug, glued with a two-part epoxy to the bottom of the porous tube. The plug shall be a 0.75-inch as supplied by Reeves Plastic Pipe, 4295 Kearney Street, Denver, Colorado 80216, or equal.

Two-part epoxy.—A two-part epoxy suitable to hold PVC fittings to the porous tube is available at most hardware stores. Fast setting or 5-minute epoxies are not recommended.

EDI–17, Porous-Tube Piezometer Casing (Embankment Installations)

Porous-tube piezometer protective casings consist of the following: PVC influence zone, reducer assembly, riser casing, riser couplings, metal screen, and a PVC plate.

PVC influence zone.—The PVC influence zone shall consist of an 11-foot section of 6-inch-inside-diameter, schedule 80 PVC pipe conforming to ASTM Designation: D 1785, with the reducer assembly cemented to both ends.

Reducer assembly.—The reducer assembly consists of a 6- by 2-inch schedule 80 PVC reducer coupling conforming to ASTM Designation: D 2467. A liquid weld cement is used on all joints, conforming to ASTM Designation: D 2564.

Riser casing.—The riser casing shall consist of 10-foot sections of 3-inch inside diameter schedule 80 PVC pipe conforming to ASTM Designation: D 1785. The casings are connected by the riser couplings as shown on the drawings.

Riser couplings.—The riser couplings shall consist of a 2-foot section of 4-inch inside-diameter schedule 80 PVC-pipe conforming to ASTM Designation: D 1785.

Metal screen.—Metal screen shall be No. 8 gauge mesh bronze or brass wire cloth.

Cloth.—Cloth used to wrap the piezometer influence zone shall be fashioned out of burlap or cotton 2 by 6 feet long.

EDI–18, Porous-Tube Piezometer Standpipe

The standpipe shall consist of 10-foot sections of ¾-inch inside diameter, flush-coupled, schedule 80 PVC pipe with 8 square threads per inch. Flush couplings shall be reamed and threaded joints, as manufactured by Timco Manufacturing Company, Inc., Prairie du Sac, Wisconsin 53578, or equal. See figure EDI–18 for details.

Liquid weld cement.—Liquid weld cement conforming to ASTM: D 2564 shall be used for installing the porous tube to the standpipe.

EDI–19, Water Level Indicator

The water-level indicators shall consist of a cable reel, cable 200 feet long, two ⅜-inch outside diameter sounding probes (one attached and one extra), and a carrying case. The water-level indicators shall be model No. 51453, as provided by Slope Indicator Company, 3668 Albion Place North, Seattle, Washington 98103, or equal.

EDI–20, Slotted-Pipe Piezometer

Slotted pipe.—Pipe shall be 1.5-inch inside diameter schedule 80 PVC pipe, 10 feet in length; shall have three rows of slots cut on 120° centers with the 0.01-inch wide slots of each row being 0.25 inch apart; and shall be provided by the manufacturer with an internal plug at the bottom end and an internal reducing bushing of the proper size to accept the standpipe to the top. In no case shall the outside diameter of the slotted pipe with plug and bushing exceed 1.9 inches. Slotted pipe shall be as manufactured by Timco Manufacturing Company, Inc., Prairie du Sac, Wisconsin 53578, or equal.

Plastic standpipe.—The standpipe shall consist of 10-foot sections of ¾-inch-inside-diameter, flush-coupled, schedule 80 PVC pipe with 8 square threads per inch. Flush couplings shall be reamed and threaded joints as shown on figure EDI–18. Plastic standpipe shall be as manufactured by Timco Manufacturing Company, Inc., or equal.

EDI–21, Pneumatic Settlement Sensor

A pneumatic settlement sensor monitors the difference in elevation between the sensor and its reservoir. The water pressure transmitted between the sensor and the reservoir by a hydraulic water-filled tube is balanced by an opposing pneumatic pressure, and any chance in elevation of the sensor is exactly reflected by a pneumatic pressure change transmitted through the bundle to a readout instrument. Water pressure within the pneumatic settlement sensor shall be balanced by air pressure against a flexible, nonmetallic diaphragm which acts as a valve venting all excess pressure within the opposing pneumatic circuit to the atmosphere through a separate vent tube. The settlement sensor shall be designed in such a manner that a slight flow of gas (tubing described in EDI–6) must be maintained to obtain accurate readings. The pneumatic settlement sensor shall not require in-place calibration. The pneumatic settlement sensor shall be capable of accurately measuring settlement to plus or minus 0.1 foot and be able to measure settlements over a range of 0.5 foot to 101 feet as a maximum value of elevation difference between sensor and reservoir.

Calibration curves or settlement unit-induced, spring-load factors shall not be necessary to take the readings or reduce the instruments's data. Each settlement sensor shall be provided with an individual water reservoir for the purpose of allowing reading to be taken during construction, and additionally, each sensor shall be capable of being attached to the common reservoir once it has been installed. The liquid used to fill the hydraulic leads (described below) shall have a specific gravity of 1.0 which will not cause any adjustment to be made on the readout gauges. This liquid shall be a controlled mixture of ethylene glycol, methanol, and water. The mixing ratio shall be 655 units ethylene glycol to 345 units methanol which produces a pure antifreeze with a density of 1.0. The percentage of water shall be 60 percent which will provide freezing protection to a minus 29 °C. Mercury, which is toxic when contacted by the operator externally, shall not be allowed anywhere in the settlement sensor system. The pneumatic settlement sensors shall be as manufactured by Slope Indicator Company, 3668 Albion Place North, Seattle, Washington 98103, model No. 51483, or equal. In addition, the manufacturer shall furnish a portable system that is capable of flushing the hydraulic lines of the pneumatic settlement sensor of air and replenishing the liquid in the hydraulic lines. This system shall be capable of being used in the terminal well at the common reservoir or at each individual reservoir during installation. The portable flushing system shall be a Nold DeAeriator as manufactured by Walter Nold Company, 24 Birch Road, Natick, Massachusetts 07160, or equal.

Reservoirs.—Settlement sensor reservoirs shall be of adequate size to accept all tube bundles of the settlement sensors assigned to the respective terminal well or instrument house. The reservoirs shall be capable of being secured to a wall in the terminal well or instrument house as shown on the drawings to provide a fixed reference level. The terminal well reservoir must be sized to allow it to fix through the hatchway of the terminal well. The reservoirs shall be filled at the factory, and their design shall be such as to prevent evaporation and to compensate for temperature changes. The reservoir shall be as manufactured by the Petur Instrument Company, Inc., or equal.

Pneumatic settlement indicator.—The pneumatic settlement indicator shall be capable of being connected to the gauge box used with pneumatic piezometers on its input side and to the tube bundle terminal assemblies on is output side through the use of connecting leads as described in paragraph EDI–8. The pneumatic fittings for the pneumatic settlement indicator's input and output shall be Hansen B2–K16 plug fittings. Two metal dust caps with attaching chains shall be furnished for each plug fitting furnished. The pneumatic settlement indicator shall have a test gauge of the double-rotation type with a 6-inch dial face, mirror parralax control, automatic temperature compensation, manual zero control, a gauge accuracy of plus or minus 0.1 percent over its full 60-lb/in^2 range, a repeatability of plus or minus 0.03 percent full scale, and a sensitivity of plus or minus 0.01 percent full scale. Reading increments shall be 1-lb/in^2 units. The settlement indicator shall be as manufactured by Petur Instrument Company, model No. SC–100, or equal.

Hydraulic tube bundle.—The connecting hydraulic tubing from the pneumatic settlement sensor to the hydraulic reservoir shall be polypropylene tubing constructed of a stabilized polypropylene plastic having an air absorption of 0.02 percent and a minimum burst pressure of 500 lb/in^2. For the purpose of tube identification, the tubes within a bundle shall be of different colors as recommended by the instrument manufacturer. The tubes shall be a maximum of ¼-inch outside diameter and the tube bundle shall be covered by a polyethylene continuous sheath. No splices or connections will be permitted in the polyethylene sheath or polypropylene tubes between the pneumatic settlement sensor and the hydraulic reservoir.

The individual hydraulic tube bundles will be cut to the length required and attached to the pneumatic settlement sensor by the manufacturer. Lengths required will include the length needed in trenches, length to instrument house at the top of the dam, additional 10 percent for slack, and an extra 10 feet per unit. The manufacturer shall provide an individual hydraulic reservoir on each liquid-filled hydraulic tube bundle using connectors which shall be compatible with the common reservoir connectors to which the hydraulic tube bundle is to be attached in the instrument house. The manufacturer will ship each settlement sensor and its tube bundle and individual reservoir to the field as a unit.

EDI–22, Vibrating-Wire Settlement Sensor

Vibrating-wire settlement sensor.—A vibrating-wire settlement sensor monitors the difference in elevation between the sensor and its reservoir. The water pressure transmitted between the sensor and the reservoir by a hydraulic water-filled tube bundle is measured by a transducer capable of transforming a piezometric pressure into resonant frequencies which can be transmitted and displayed. The settlement sensor shall have sensitivity of ±0.80 inch over its entire range (between the settlement sensor and its reservoir) of 0 to 100 feet using a 30-lb/in^2 pressure transducer. The size of the sensor shall not exceed 4 inches in diameter by 6 inches in length. All materials for the settlement sensor shall be PVC and stainless steel, except the vibrating wire. The interior of the sensor shall be hermetically sealed to provide a stable, inert atmosphere around the wire to ensure long life of the transducer. The electrical cable shall be as described in EDI–12. The hydraulic leads connected to each settlement sensor shall be as provided in EDI–21. Each settlement sensor shall be provided with an individual water reservoir for the purpose of allowing reading to be taken during construction, and, additionally, each sensor shall be capable of being attached to the common reservoir once it has been installed. The liquid used to fill the hydraulic leads (described in EDI–21) shall be a controlled mixture of ethylene glycol, methanol, and water. The mixing ratio shall be 655 units antifreeze with a specific gravity of 1.0. The percentage of water shall be 40 percent which will provide freezing protection to −52 °C. Mercury, which is toxic when contacted by the operator externally, shall not be allowed anywhere in the settlement sensor system. The vibrating-wire settlement sensor shall be as manufactured by Geokon, 7 Central Ave, Lebanon, New Hampshire 03784, model No. 4650 or equal.

In addition, the manufacturer shall furnish a portable system that is capable of flushing the hydraulic lines of the settlement sensors of air and replenishing the liquid in the hydraulic lines. This system should be capable of being used in the terminal wells and the canal works control house at the common reservoirs, or at each individual reservoir during construction. The portable flushing system shall be a Nold DeAerator, or equal, as manufactured by Walter Nold Co., 24 Birch Road, Natick, Massachusetts 07160.

EDI–23, Inclinometer Casing and Couplings

Inclinometer casings and couplings.—Inclinometer casings and couplings shall be constructed of self-aligning, precision extruded aluminum, with an all-surface anodized protective coating, and four full-length internal wheel track grooves, spaced at 90°, as manufactured by Terra Technology Corporation, or equal, 3860—148th Avenue NE., Redmond, Washington 98052. The casing sections shall be furnished in 10-foot lengths with an outside diameter of 3.38 inches. Casing sections installed in drill holes shall be butt-jointed (see figure EDI–23a) and shall utilize couplings 6 inches long.

Casing sections installed in the embankment shall have telescoping joints (see figure EDI–23b) and shall utilize couplings 24 inches long. The 24-inch couplings will provide a 1-foot space between casing sections at each joint. All casings and couplings shall have matching grooves to provide for self-aligning installation and to ensure that the spring-loaded wheel assemblies of the sensor probe will remain in the same groove set for the entire length of the installation. Each 10-foot length of inclinometer casing installed in the embankment shall have an aluminum settlement flange attached to its midpoint. The settlement flanges shall be model No. 51006 as manufactured by the Slope Indicator Company, or equal. Two aluminum inclinometer casing caps shall be provided for each installation such as model No. 51005 as manufactured by the Slope Indicator Company, or equal. Eight extra aluminum inclinometer casing caps shall be provided to the Government. All pop rivets shall be aluminum, with eight rivets required for each coupling. Model No. 51033-1, AD43H rivets are to be used for the 24-inch long couplings. The model numbers listed are for rivets furnished by the Slope Indicator Company; however, any aluminum pop rivet of equal size and quality may be used.

Backfill materials.—To backfill drill holes, a mixture of one part cement to three parts sand, by volume, shall be used to backfill the annular spaces between the aluminum casings and the sides of the drill holes. The backfill shall be pumped under pressure from the bottom of each drill hole up to the foundation/embankment contact as shown on the drawings. To backfill the area around the casings in the embankment from the foundation to the collar protective pipes, only embankment materials shall be placed and compacted to the density and at the same moisture content as the adjacent embankment materials. To backfill the area around the outside of the collar protective pipes, as well as the annular spaces between the insides of the collar protective pipes and the aluminum inclinometer casings, a grout mixture of one part cement to three parts sand, by volume, shall be used.

Protective pipe and cover assemblies.—The top of each inclinometer casing installation shall be protected with a 1-foot diameter, 2-foot long, schedule 40 steel pipe and lockable cover (see figure EDI-23c).

Inclinometer target cap. ·Inclinometer target caps as shown on the figure EDI-23d shall be made of aluminum.

Storing materials for installation and monitoring of the inclinometer system.—All inclinometer sensors, cables, readouts, casings, couplings, caps, and incidental hardware shall be stored in a clean, safe area. Any inclinometer casings, couplings, or caps that are damaged by mishandling will be rejected by the Government for use, appropriately marked with yellow spray paint, and shall be replaced.

EDI-24, Inclinometer Probe and Cable

Inclinometer probe.—The probe shall contain two internal, orthogonally mounted servo-accelerometers in a waterproof housing capable of rapidly measuring in English units the probe's angle of inclination from the vertical in two perpendicular planes. The minimum acceptable sensitivity shall be plus or minus 0.0001 foot of lateral movement per 2 feet of casing. The probe's operating range shall be plus or minus 90° from the vertical. The probe shall be capable of operating within any currently available square or grooved inclinometer casings ranging in size from 1.50- to 3.44-inch inside diameter without modification to the probe or to the wheel assemblies.

The probe's wheel assemblies, sometime called wheel guides, shall be spring loaded and mounted to the probe in such a manner that the probe is centered within any of the square or round inclinometer casings available without changing wheel assemblies, individual wheel assembly components, or modifying any part thereof. Any wheel assembly that cannot keep the probe centered and in the desired track, while passing through any settlement or butt-joint casing coupling, is not acceptable to the Government. The gauge distance, or wheel base of the inclinometer probe, which is the distance between axis pivot points of the wheel assemblies, shall be 2.0 feet. The outside diameter of the probe shall not exceed 1.0 inch exclusive of wheel assemblies, and the total length of the probe shall not exceed 30.0 inches.

A cover shall be provided to protect the cable coupling at the top of the inclinometer probe. This protective cover shall prevent mechanical damage to the coupling and provide a water and dustproof cap over the entire coupling whenever the inclinometer suspension cable is disconnected from the probe.

A metal carrying case shall be furnished with the probe. This carrying case shall provide the probe protection, both during storage and during transportation to and from the measuring site, from incidental damage and excessive mechanical shock and vibration.

The inclinometer probe shall be a model No. 50325 as manufactured by Slope Indicator Company, 3668 Albion Place North, Seattle, Washington 98301, or equal.

Inclinometer suspension cable.—The inclinometer suspension cable shall be of adequate length of all holes on the project with couplings compatible with the couplings on the probe and the indicator-cassette recorder. The inclinometer suspension cable shall be a continuous length with no splices or other defects. The limits of its outside diameter shall be 0.42 inch. It shall have a continuous unspliced stranded steel core and a one-piece waterproof neoprene jacket for its entire length. The suspension cable shall contain adhesive layers between the stranded steel core, the individual electrical conductors, and the neoprene jacket to prevent creep and slippage during use. The cable shall be marked at 1-foot increments by means of external bumps vulcanized to the external neoprene jacket. Red shall be utilized for the 1-foot marks and yellow shall be used for each 10-foot mark. The external marks shall indicate the distance from the measuring point on the pulley assembly at the casing collar to the midpoint between the wheel assembly axes on the inclinometer probe.

Cable reel.—The cable reel shall be a handcrank-operated cable reel assembly capable of holding the inclinometer cable described earlier. The reel is to include a protective case and all mechanical and electrical connectors, with protective covers, needed to operate the inclinometer system. The reel shall be of such design as to allow operation of the inclinometer system while the drum is rotating. All mechanical and electrical components of the cable reel are to be accessible for field servicing. The cable reel shall be a Slope Indicator Company model No. 50501, or equal.

EDI-25, Inclinometer Recorder-Processor-Printer and Data Transmittal System

(Recorder-Processor-printer) RPP.—The RPP shall be field portable, contained within a single protective carrying case, and shall be capable of being used during adverse weather conditions. The RPP is to be powered by either internal rechargeable batteries or an external 12-V direct-current automotive-type source. The internal batteries must be capable of powering the RPP for a minimum of 16 hours from a single charge. A means for monitoring the RPP's operating power supply shall be provided. The internal batteries shall be capable of being recharged from either the U.S.A. standard 110-to 120-volt alternating-current, or a 12-volt, direct-current power source. During charging of the batteries in cold weather, an extra connector port and electrical circuit shall be required so that the internal rechargeable batteries are not destroyed.

A 50-foot long power cable with appropriate connectors shall be furnished to operate the indicator from the external 12-volt direct-current power source. On the RPP's control panel face all switches, data displays, and other components shall have their functions clearly and permanently marked. The data displays shall be of the LCD type with 32-character by two lines.

The RRP shall be capable of displaying input data from the inclinometer probe on the control panel as well as recording the input data on an internal memory and a magnetic tape cassette for storage and playback. The RRP shall be capable of recording on the magnetic tape external data such as the date, well number, and sensor orientation within the casing in addition to the information relayed by the probe concerning the two accelerometer outputs and its depth within the casing. When the RRP is in the playback mode, it shall play back at a 300-baud rate through a RS-232C interface, and all data output through the interface shall be in the ASCII format.

The RPP shall have a 20-K CMOS static RAM memory with internal battery backup. The RPP shall microprocessor based computer with an alphanumeric keyboard with 50 pressure sensitive keys; a real time clock of seconds, minutes, hours, day, month, and year with battery backup; a memory capable of handling a complete set of data up to at least 700 feet in depth in 2-foot increments; and an electrostatic printer of 32 characters per line with paper takeup and power switching in the program. The RPP shall have an output/input for an EIA RS-232 compatible device at 75 through 9,600 band rates. The magnetic-tape cassette shall be capable of holding multiple data files up to 127 data files per side of the tape.

All data output shall be compatible with the Bureau of Reclamation's CCS (Central Computer System) in Denver, Colorado. The RPP recorder shall be model No. 50368, as manufactured by Slope Indicator Company, Seattle, Washington, or equal.

Data transmittal system.—The data transmittal system shall consist of all equipment and materials necessary to interface the output played back from the RPP with the Bureau of Reclamation CCS in Denver, Colorado, through any existing time-sharing computer terminal located at the Bureau of Reclamation project office. The terminal is equipped with interfacing couplings and a modum at the site; the data transmittal system should be equipped with RS-232C interfacing couplings. All existing equipment operates at the 300-baud rate.

Equipment furnished for the data transmittal system shall include, but not be limited to, supplying a data selector switch, Slope Indicator model No. 50308-55, or equal, as manufactured by Slope Indicator Company, Seattle, Washington, and supplying all necessary interfacing leads with the proper couplings attached.

A minimum of two operating and maintenance manuals shall be provided with the inclinometer system. These manuals shall include as a minimum the specifications of the inclinometer system, a description of the major assemblies, instructions for operation and periodic maintenance procedures, and a complete electrical and electronic schematic diagram suitable for troubleshooting by an electronics technician.

EDI-26, Extensometers

Extensometer assembly.—An extensometer assembly consists of sensing rods, anchors, protective covering, reference head, armored cable, and readout.

Sensing rods.—Each sensing rod shall be 0.1875- to 0.250-inch-diameter aluminum (6061-T6) or stainless steel and shall be assembled continuous for their full length between the anchors and the spring elements in the reference head.

Anchors.—All anchors used in the extensometer shall be made to fit in a 3-inch-diameter hole and have sensing rod permanently attached. The anchors shall be capable of first being expanded against the walls of the hole by use of hydraulic pressure and secondly, capable of then being grouted into place. Each anchor shall be provided with a check valve at the anchor which will hold the hydraulic pressure in the anchor once the line for pressurizing is detached. All hydraulic tubing needed to expand the anchors shall be provided, along with a good quality aircraft hydraulic fluid (SAE 20) and all necessary pressurizing equipment. All tubing shall be ⅛-inch diameter high-pressure tubing. Each extensometer assembly shall be provided with an anchor for installing the extensometer in the drill hole. These anchors shall be of the same design as the extensometer anchors except it shall be provided with a pulley and ¼-inch-diameter rope of adequate length to pull each extensometer into the drill hole.

Protective covering.—Each sensing rod shall be enclosed in a protective covering such that the rods will be able to move freely and the covering shall be flexible enough to allow a minimum of 4 inches of movement to take place between the reference head and the anchor. This covering will also allow no friction to take place between adjacent sensing rods. A second protective covering shall be used to cover the first covering and all other sensing rods between anchors. This second covering shall be flexible allowing 4 inches minimum movement to take place between each anchor and allowing the sensing rods to move freely within.

Reference head.—Each extensometer shall be provided with a detachable reference head, capable of both electrical and mechanical readout capabilities. Each reference head shall be raintight, dusttight, and corrosion resistant. The reference head shall be manufactured to attach to and provided with a 3-inch schedule 40 steel galvanized protective pipe. The reference head shall also be capable of tensioning the sensing rods to approximately 75 pounds with springs that have 25-lb/in load rate. The minimum range of the sensing rods travel shall be 4 inches and the reference head shall be capable of electrically and mechanically measuring this movement. The measuring range shall be able to be reset should any rod reach maximum extension. The reference head shall be provided with a watertight electrical connector to which an armored cable connects. A micrometer or similar precision measuring device for making mechanical readings in case of primary system failure shall be provided.

Armored cable.—Each extensometer assembly shall be provided with the required length of armored cable. On both ends of the cable connectors shall be provided, one to attach to the reference head and the second to attach to the manufacturer's readout apparatus. The armored cable shall be watertight and made for direct burial under earth.

The extensometer assembly shall be a model No. 8-CSLT(R) as manufactured by Slope Indicator/ Terrametrics, Inc., or equal.

Readout unit.—A readout unit capable of measuring the five different anchor movements shall be provided. The unit shall be portable and a multiple range unit. The unit shall be equipped with a rechargeable battery and battery charger included. The unit shall be equipped with an LED display and capable of reading movements to 0.001 inch. The unit shall have the capability to directly read the extensometer by attaching to its connector on the armored cable.

Readout unit shall be model NO. DC-6 as manufactured by Slope Indicator Co., Seattle, Washington, or equal.

EDI-27, Shear Strip Device

Shear strip—The shear strip device consists of two copper conductors which form two long parallel paths connected together by resistors at set intervals. The length and particular interval spacing of the resistors are selected to suit particular applications. The standard spacing of the resistors is 3 feet but can be as little as one-half foot. Larger spacings can be used and the spacings can be varied along the strip so that particular zones of interest can be covered by closely spaced elements, with wider spacings elsewhere.

The resistors used are 10K-ohm ± percent. The entire assembly is waterproofed with three coats of PVC paint.

Electrical leads (zip cord).—The two ends of the shear strip are connected to flexible electrical leads (zip cord). When grouted in place, the lead from the far end of the shear strip is doubled back alongside the shear strip so that both leads issue from the mouth of the borehole. If required, intermediate zip cord leads can be connected at any point along the strip. These may be desirable if the number of resistors is large, in which case the shear strip can be made up of several electrically isolated segments. Each pair of zip cords is terminated with a 4-pin plug, type MS 3102-A18-4S.

Readout box.—The readout box, model No. 52852200, for use with the resistive shear strips, is composed of a null-balance galvanometer along with a 3-digit binary-current switch.

The parallel resistance network in the shear strip circuit is connected in one arm of a Wheatstone bridge circuit and is balanced by a 3-digit binary-current switch in another arm of the bridge. The box includes a battery test position.

The box uses replaceable D size batteries, and the external connector is MS 3012-A18-4D. The box measures 8 by 6 by 4 inches and weighs 3½ pounds.

All shear strip equipment can be purchased through Slope Indicator Co., Seattle, Washington, or equal.

EDI-28, Tiltmeters

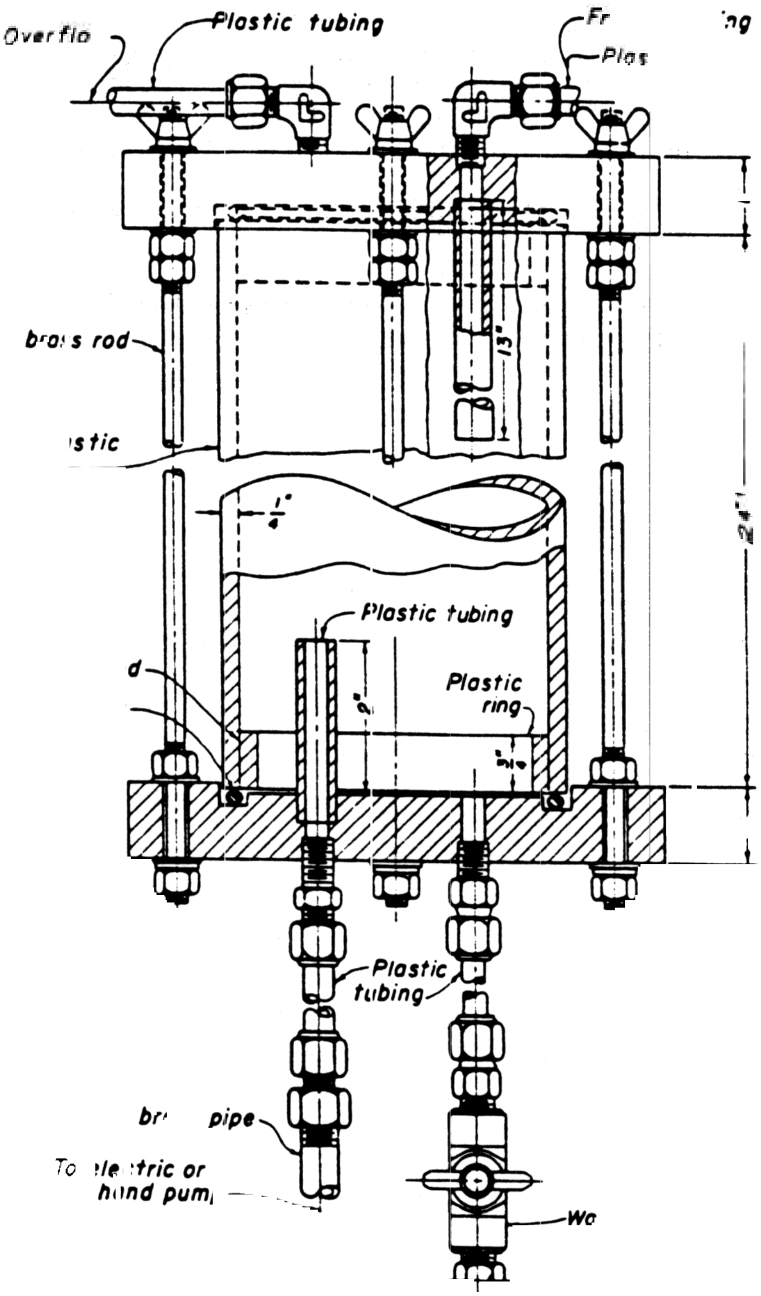
Tiltmeters consist of three basic parts: the sensor, mounting plates, and readout indicator. The system which has not been used yet by the Bureau is described in paragraph 4 below.

(1) Tiltmeter sensor.—The portable tiltmeter sensor utilizes a closed-loop, force-balanced servoaccelerometer specifically designed for horizontal tilt measurements. The sensor senses changes in tilt of the mounting plates. To operate, the sensor is oriented on three pegs of the mounting plate and an angle is read on the four-digit indicator display. Sensor has a range of ±30° from vertical, with a sensitivity of 1 part in 10,000 (10 seconds of arc are equivalent 200 microinches elevation difference on the pegs). Sensor model No. 50322 as manufactured by Slope Indicator Company, is 6-inch diameter semicircular base, 3 inches high. The material has a steel base with the accelerometer in an aluminum housing.

(2) Mounting plate.—The mounting plates are casts from specially formulated porcelain with four sensor orientation pegs in the upper surface. Using grout or epoxy resin, the plates are bonded to rock, concrete, or metal. They are inexpensive, durable, noncorrosive, and have high dimensional stability. Ceramic tilt plate, model No. 50323, as manufactured by Slope Indicator Company, is 6-inch diameter by ¾-inch thick with four pegs equally spaced 4 inches apart.

(3) Readout unit.—The readout unit for the tiltmeter sensor can be the same unit used for the inclinometer described in section EDI-25.

(4) Tilt sensing system.—The tilt sensing system consists of four basic parts, tilt sensor, mounting plate, console, and recorder.



PLASTIC AIR TRAP
PIEZOMETER TERMINAL WELL

Figure EDI-3.

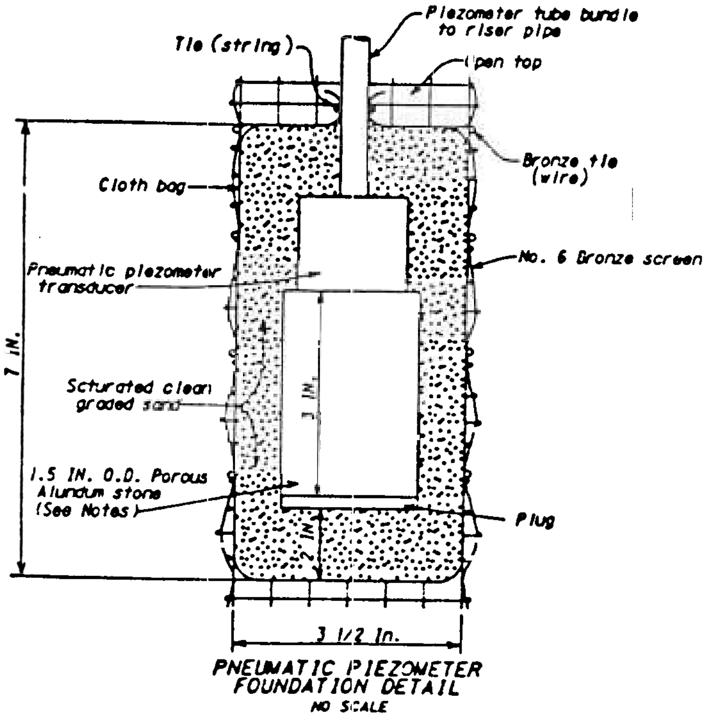


Figure EDI-5.

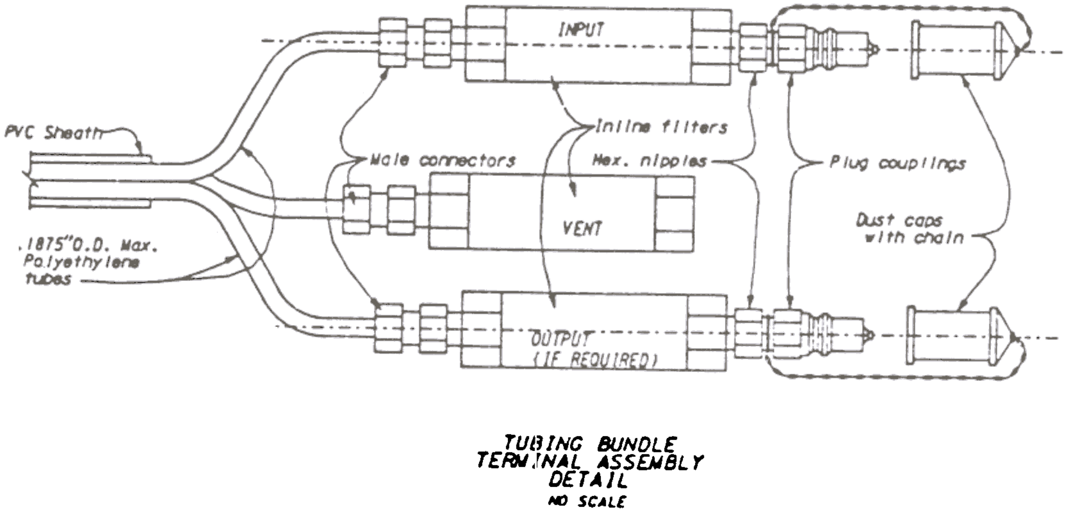


Figure EDI-7.

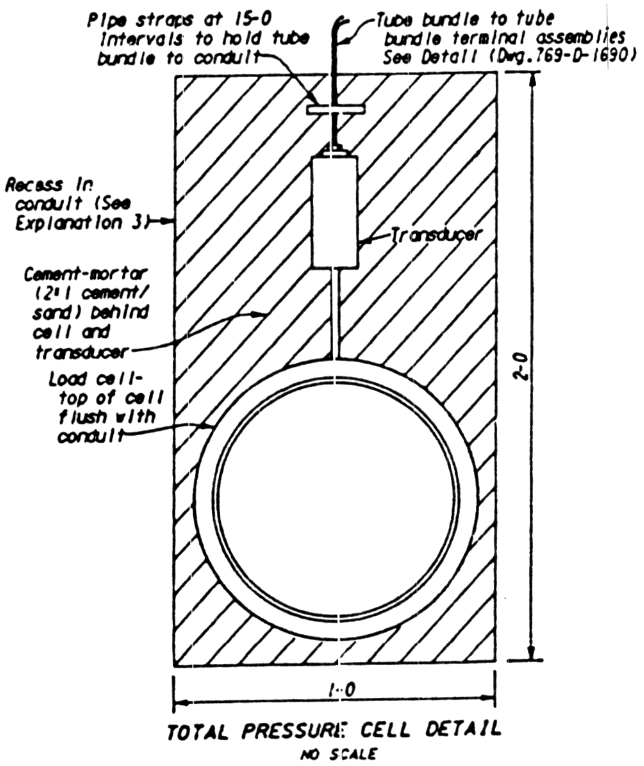


Figure EDI–15.

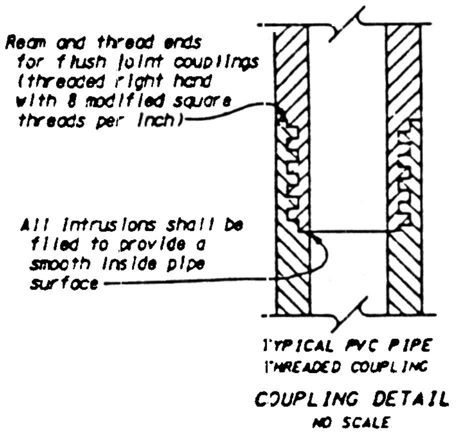


Figure EDI–18.

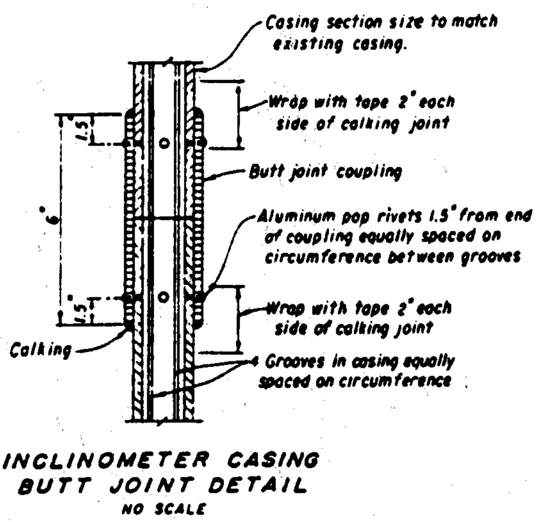


Figure EDI-23a.

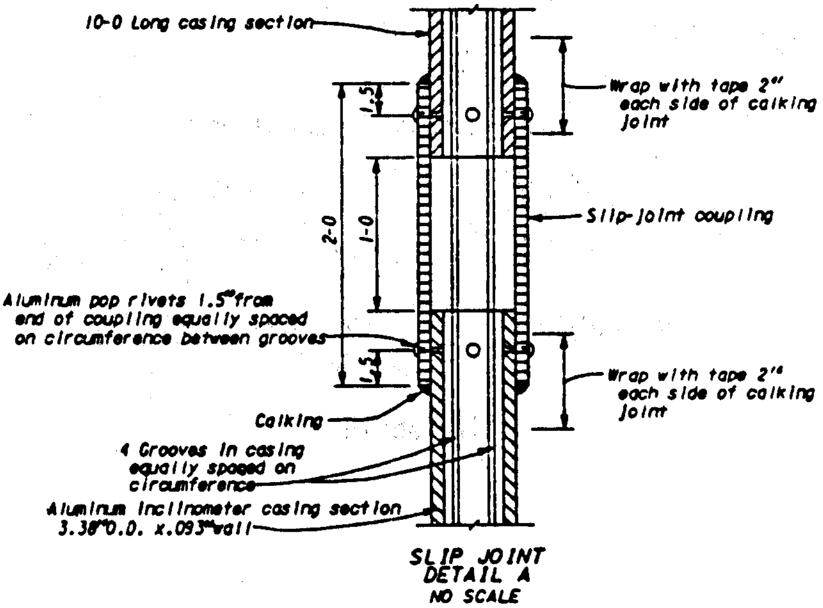
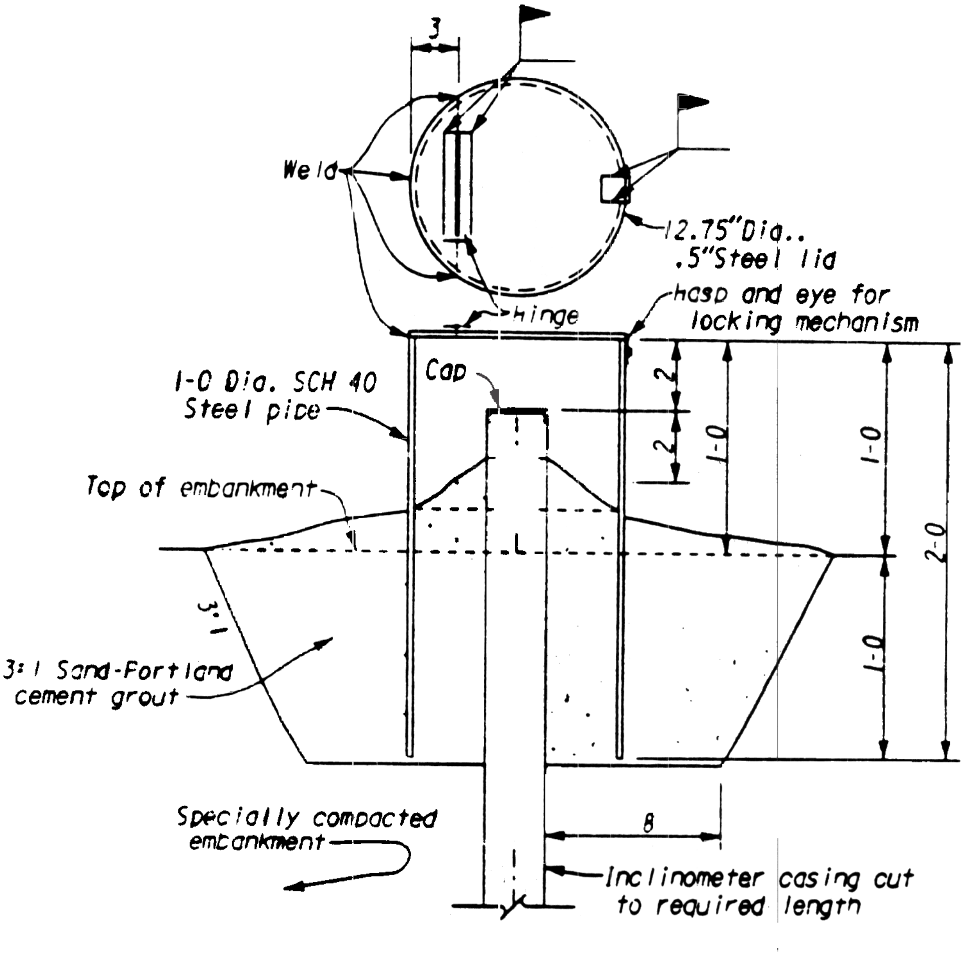


Figure EDI-23b.



PROTECTIVE PIPE AND COVER ASSEMBLY
NO SCALE

Figure EDI-23c.

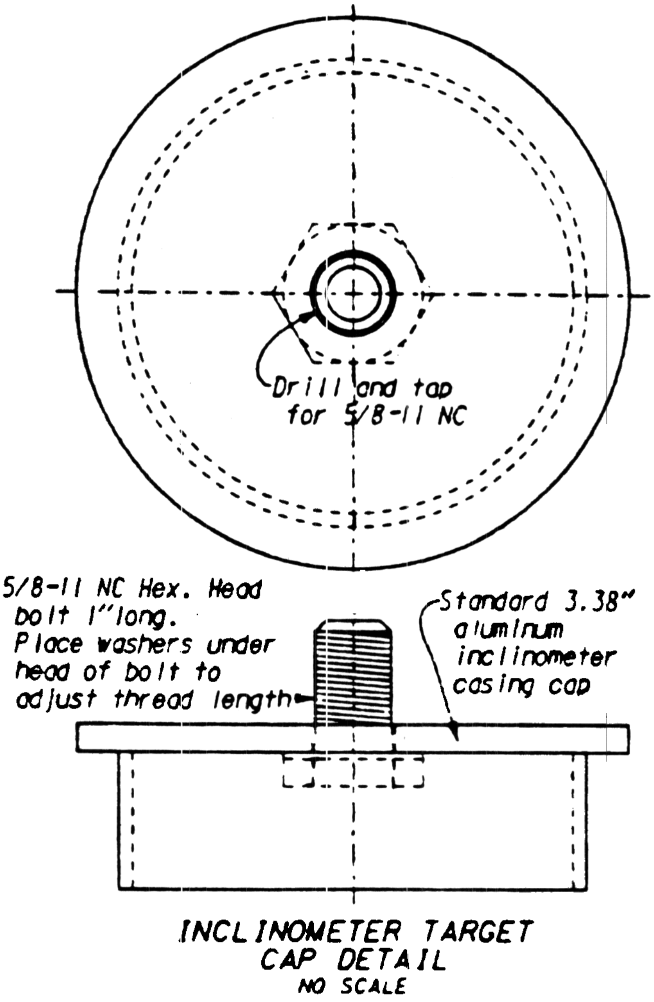


Figure EDI-23d.

APPENDIX B
EMBANKMENT DAMS INSTRUMENTATION DATA PROCESSING

Appendix B

EMBANKMENT DAMS INSTRUMENTATION DATA PROCESSING

by Lawrence W. Gilchrist

Introduction

The reduction, processing, and presentation of instrumentation data by the Embankment Dams Section provide an efficient and effective method for the interpretation of structural performance data. Each year, nearly a million new data points are processed. These data points are added to an existing data base of over 40 million data points.

The growing demand for more accurate and timely data interpretation has led to the development of the current processing system. Using computers to process and perform historical comparisons and plotting functions once done by hand has given the reviewing engineers more time and a choice of a variety of presentations to aid in the evaluation of embankment dam structural behavior.

The current data processing procedures are described in this text and in the two appendices. The first appendix contains the figures referenced in the paper, and the second is a glossary of definitions for all the abbreviations and program names used.

I. General Data

A. Receiving and Processing Data

Data are received by the Embankment Dams Instrumentation Section (D-3352) by four different means of transmission: computer (CYBER), mail, telephone, and by automated transmission.

1. **Computer.**—Approximately one-half of the instrumentation data received (not including inclinometer data) are transmitted through the CYBER system. These data are from the 70 dams which currently have the facilities to use the "GO" program. This program accepts raw data input from either of two sources: through keyboard entry interactively with the "GO" program and with TELXON, a hand-held computer (electronic clipboard).

a. **CYBER.**—The majority of data are entered through the CYBER system using the "GO" program interactively. Field personnel run the program which prompts the individual instruments (Label) and the operator responds with the appropriate reading. Figure B-1 shows a sample of how a data entry session might progress. The readings which are entered are raw numbers (i.e., depth to water for piezometers, rather than elevation). After entering all the readings, the operator uses the same "GO" program to process and receive a printout of the data. Processing includes the necessary calculations needed to convert data into more meaningful numbers (i.e., the elevation of water from a raw depth to water reading). This internal processing saves time and eliminates arithmetic errors. The printout has two columns indicating changes; one is the change since the previous reading and the other is the change from the initial reading.

b. **TELXON/CYBER.**—The TELXON instrument is designed to be used in the field. The program provides for the instrument names (Labels) to be prompted in the order the readings are normally taken. The observer is prompted with the Label and then the previous reading and data. The Labels can be prompted by groups of instruments (Types) or by mixing Types. There is an internal clock to record the date and time that the readings are taken, and an editing procedure to correct improperly entered readings. After the readings have been entered, the TELXON is taken back to the office where it is interfaced with the computer terminal and a file containing all the data is sent to CYBER. The "GO" program is then used to process the data and produce a printout of what was recorded.

Figure B-2 shows how the field recorder would use the "GO" program to process the field readings and receive a printout. With the printout, the observer in the field has the first opportunity to spot anomalies. If an anomaly is simply a data entry error, the "GO" program affords the recorder the opportunity to change the raw reading by editing the data file and then reprocessing it. When the recorder is satisfied the readings are accurate, the recorder can then select to (KEEP) the data. This selection does three things: it routes a copy of the printout that the field office received to the E&R (Engineering and Research) Center in Denver and to the appropriate regional office, it updates the data files on the CYBER, and it creates a file on the CYBER to be added to the existing data base residing on Hewlett-Packard microcomputers at the E&R Center.

Manuals have been prepared, complete with examples, which describe in more detail how field personnel can use this program with their equipment to send instrumentation data. These manuals are available from the Structural Behavior Branch.

2. **Mail or Telephone.**—Observations on the majority of the dams (about 70 percent) involve data sent through the mail. Typically, these are dams with a monthly (or less often) reading schedule, and accounts for about 45 percent of the total daily volume of data entry. Data are received either from the damsite or indirectly from the project office. The Embankment Dams Instrumentation Section has developed a set of standardized forms for each instrument type. These developed a set of standardized forms for each instrument type. These forms have been mailed to all the dams. Figure B-3 is an example of a form used for recording hydraulic piezometer readings.

Once the data are received at the E&R Center, the data sheet is attached to a work order form and is given to the processor who is assigned to that dam. The processor then types these data directly into the data base. Data are received over the telephone when readings need to be analyzed more quickly than the mail can accommodate. Data received by telephone are recorded on sheets similar to those mailed in by the field. Once the data are received, they are handled the same as mailed data, except the data are expedited through the system. Data sent through the computer are processed faster than that which are telephoned in and entered by hand, so dams with computer capability do not need to telephone in data.

3. **Automated Transmission.**—Our office also receives data from dams which have the reading and transmission of these data automated. Each of the instruments scan and report the data according to a specific schedule. For example, vibrating-wire piezometers may be read every 4 hours, while pneumatic piezometers may be read once a day. These schedules can be changed from the site or changed remotely across a computer telephone hookup. Each group may also scan and report readings upon request of a user. Figure B-4 is an example of the automation at Calamus Dam and illustrates how their data may be received.

a. **Satellite.**—The Embankment Dams Instrumentation Section has the capability of receiving satellite data through the cooperation of the Atmospheric Water Division's receiver dish and downlink system. They collect the data from the "GOES" satellite, which have been sent from the data control platform at the damsites. The data are then moved onto files on the CYBER. From there a program called DECODE will automatically run and process the satellite coded file. Next, it will append the reduced data onto the file which is brought over with the SENDALL program, and the data are added to the existing data base.

b. **Telephone.**—A data processor can also dial directly into the computer at the damsite and receive a report of readings over a computer terminal at the E&R Center. The user calls the data control platform and interactively instructs the computer to scan and/or report on the instrument readings. The readings are handled the same as data telephoned into the office by field personnel.

B. Entering the Data Base

. Description of Data Base.

a. **Hardware.**—All the computer data for the Embankment Dams Instrumentation Section's office reside in files stored on a Hewlett-Packard 132-megabyte hard disk. This hard disk is accessed by nine H-P microcomputers all of which are on an SRM (Shared Resource Management) local area network. The nine include four 9845's, two 9835's, three 9816's, and one 9836. Each of these computers can spool printouts to one of two printers (model 2631) or spool plots to either of two plotters (model 7550). We also have three other plotters (model 9872), a letter quality printer (model 2601), a digitizer (model 9874), and telephone modems are also available.

The Embankment Dams Instrumentation Section uses 9835's and 9845's to enter and plot all the embankment dam data. The 9845's have screen graphics, and the image may be transferred to a thermal plotter (neither are in color). Because the 9835's are more limited in their functions and are slower machines, they are used primarily for data entry. Each of these machines can also be used as a CYBER terminal.

b. **Software.**—The data are stored on the SRM in a tree structure of separate directories as illustrated on figure B-5. On the root level, there are three main divisions: E-directory for embankment dam data, C-directory for concrete dam data, and the spooler directories for the plotters and printers. Under the E and C directories, separate directories exist for each dam named using the two-character dam abbreviation. Also, there are other separate directories containing the programs written for the different machines. There are 220 dams or directories under E and 65 dams under C. Within these directories are a series of files each with a unique name identifying the type of data. The first two letters are the dam abbreviation, the second two indicate the instrument type, and the remaining letters indicate the number of the file and if it is a data or a plot file.

Data files are a combination of a random and a sequential type file and contain both characters and real numbers. The first record contains the title of the file, the number of observations, the number of variables, and the names of the variables. All numeric data start at the second record and are stored sequentially from that point to the end of the file. The data are stored in a two-dimensional array, which is set up with the number of variables by the number of observations [i.e., Data (4,100) is the 4th variable and 100th observation.] All the data files are updated either manually at the E&R Center using the UPDATE program or by field personnel via the CYBER using SENDALL/UPCHUK programs. Once updated, files can be edited and printed out using the START program. Figure B-6 shows a partial listing of a file using the program START.

Plot files are used to graphically display data for easier analysis and presentation. These files contain the information needed to set up the scales and labeling of the axes for the TIMEPLOT program.

All the software was written by the staff of the Structural Behavior Branch, except for CHRMOD (terminal emulator), the EDITOR program (word processor), and the TEXT/CHARTS program (graphics display).

2. Data Entry.

a. **CYBER.**—All data which have been entered by field personnel directly into the CYBER, using the GO program, are added to the files using SENDALL and UPCHUK. The SENDALL program is used to bring the data from the CYBER over to the SRM. This is done by loading the CHRMOD, terminal emulator program into the 9845, logging on the CYBER, and running SENDALL. The program will bring over a file (ZCOLLEC) which contains all the data that have been transmitted since the last time the SENDALL program was run. This program is run at least once a day. The next step is to load the UPCHUK program, which will convert the ASCII file from the CYBER into numeric data, match the data with the correct files on the SRM, and finally update those files.

b. **Manually.**—All the data which have come through the mail or over the telephone must be typed in from the computer keyboard using the UPDATE program. The program runs interactively to prompt the processor through each step of data entry. It will ask for the two-letter abbreviation for the dam and the type of data to be entered. Next, it will prompt for the raw readings to be entered from the data sheets, in a manner similar to the way the data were recorded by field personnel. UPDATE will also ask for the raw data, so that it can do all the calculations automatically. The program loads in a file which contains all the reduction formulas and constants needed.

The program has a separate reduction subroutine which is linked to the main body of the program, that contains all the constants and formulas needed for every type of instrument for every dam. The raw and then reduced numbers are displayed on the computer before they are written to files, so that they may be corrected if entered incorrectly. File handling is transparent to the user to the point that all the user needs to know about the particular dam for which data are being entered is its two-letter abbreviation and the type of data.

There are also occasions for a commentary reading to be entered. A "DRY" reading is impossible to put into a numeric data array, but these are very meaningful data. A piezometer reading "DRY" would indicate the well was measured at least to the tip elevation, so the UPDATE program will record the tip as the reading. Readings such as "NOT READ" or "BROKEN" are stored as −9999999.99999; this number represents a missing value and could never be a true reading.

C. Checking data

1. **Comparison Sheet.**—Each time data are added to existing files, either by data entry (UPDATE) or via CYBER (UPCHUK), a comparison sheet is produced. This sheet is designed to alert the processors and reviewers to anomalies in the data. Figure B-7 is an example of a comparison sheet. There are basically two comparisons made, the change in the data since the last four observations and the change from a year earlier. These changes are printed for every instrument in each file that is updated. In this example, an observation well, OW-134, shows a large change from the previous readings. The processor will first ensure that the data were input correctly from the data sheet. If they are correct, then the reviewer is alerted and the field office is called to verify the reading. The other information at the top of the sheet is to identify the file, date of data, who entered the data, and when they were entered. The reduction program is the file containing the formulas and constants used by the UPDATE program to reduce the data.

2. **Automatic Plotting.**—When data are entered with UDPATE or UPCHUK, an empty file is created in the PLOT-QUEUE directory which identifies the dam and instrument type. Two programs, AUTO-TIMEPLOT and MPPLT (measurement point plot), will read these file names and plot the recently entered data. The gradual changes and yearly trends in instrument data are easier to identify using a plot than by using the comparison sheets.

a. **AUTO TIMEPLOT.**—It recognizes the four-letter name and will plot all the files associated with that instrument type, provided they meet two criteria. The first test depends on the type of data. As an example, observation wells are plotted every fourth time data are received, while baseplates (which are read less often) are plotted each time data are entered. The other test automatically prohibits plotting the data more than twice a month. The information about when and which observation was last plotted is stored in the plot files. An example of a plot by TIMEPLOT is shown on figure B-8. AUTO-TIMEPLOT is routinely loaded when computer usage is low, and runs unattended until the plot queue is empty or until the program is interrupted by someone needing the computer.

b. **MPPLT.**—This program will check the plot queue each time the program is run, and if a file is found, the program will tell the user that there are data to be plotted. The user may then choose whether or not to plot these data. If yes, the program will run unattended until it is finished; if no, the user may enter other files into the program. An example plot from MPPLT is shown on figure B-9.

When plots are made from either program, the two-letter region abbreviation is included. This is done because one of the two copies made of each plot is sent to the region to provide field personnel some feedback on the data which are sent.

D. Request of Plots, Printouts, and Data Corrections

Because the purpose of the Embankment Dams Instrumentation Section is to review data as received and prepare periodic reports to document structural behavior, there are constant requests for plots, printouts, and for these data to be corrected. To maintain order in these requests, reviewers must complete a form to detail these requests. This form is then given to a processor assigned to that dam with a desired date of completion. It is the processor's responsibility to complete these requests and to return the form to the reviewer.

1. **START.**—The START program is used to make all the corrections in data and in the files that contain data. The first step is to enter the file name which holds the data and from that point through the time the corrected file is stored on the disk, the program will provide a menu of options for each process. Besides editing the data, the variables may be renamed or moved between files. They may be sorted, statistics may be run, or the data may be printed. Figure B-10 shows how special function keys are provided as a menu.

2. **TIMEPLOT.**—The TIMEPLOT program plots instrumentation data versus time, as shown in the example on figure B-8. This program is the primary way all but measurement point data are presented. It plots a horizontal time axis and up to three vertical axes of different colors and eight-line types. There are plot files which organize the scaling, labeling, and variables which are on each plot. An edit routine to change these plot files is also included.

3. **MPPLT.**—The MPPLT program plots measurement point data, as in the example on figure B-9. These data are stored in a separate file for each line across the dam and they are plotted in that manner. The program uses variable names, which are the station locations, to plot the line of points for each set of readings. This plot allows reviewers to view the movement in relation to the position of the points across the dam. Each line of points represents another survey date. This program labels and scales the plot automatically unless the user elects to select an alternative scaling; therefore, plot files are not necessary.

4. **XPLOT.**—The XPLOT program plots the data from one or more variables versus another variable, rather than versus time, as shown on figure B-11. The dependent variable in most cases is the reservoir elevation.

5. **CONTUR.**—The CONTUR program gives another method of viewing data relative to their position. In this case, the data may be plotted in two dimensions on a drawing of the dam, which can show how sections of the dam (rather than individual points) behave. Measurement point data are contoured most often, because there is typically a distribution of points across the dam. Figure B-12 shows a settlement contours with 0.05-foot intervals.

The drawing with the desired instrument locations must first be digitized with the CNDIGT program and a HP9874A digitizer. The program will lead the user through each of the steps necessary to create a header file containing the locations, names, and files to produce a contour plot.

The CONTUR program uses this header file to read in all the files of the instruments digitized, then prompts the user for the date to be contoured. After all the calculations have been made, the program will plot first to the graphics and finally to a HP9872 plotter with the drawing in place. The plotting to the screen allows the operator to select the contour interval for the final plot.

6. **SEMLOG.**—The SEMLOG program plots data values versus the logrithm of time. The program does not user header files, so the operator must tell the program which variables are to be plotted from each file. Settlement data are typically the only type of data which use this plot. Figure B-13 show the settlement of measurement points.

II. Inclinometer Data

A. Receiving and Processing Data

All the inclinometer data received must be processed by the CYBER. Data are put on the CYBER by two methods: by field offices which log-on CYBER and dump the data stored on magnetic tape recorder boxes and by field sites without recorders which have written the data on forms that are mailed to our office. Each file has a specific name which can identify the dam and the date of the data. These files contain the deflection of the inclinometer probe at specific depths.

1. **CYBER.**—In order to interpret the data, files must be processed. The processors are instructed to routinely check for these (raw) data files on CYBER. The raw files are reduced by running the DEFLECT program. This program does three things, it creates files of converted data, produces three plots, and updates a header file.

The raw numbers are measured in feet of deflection, as the probe is brought up the casing 2 feet at a time. Movement is then converted into inches of deflection relative to the bottom of the hole which is assumed to be stationary. The movement is measured in four horizontal directions, all 90° apart. The A+ and A− directions are 180° opposed as are the B+ and B− directions. There are six different formulas in the DEFLECT program to convert data from all the different types of probes. With all these different raw files, there is only one format of reduced data. This new file is named with the dam abbreviation, the hole number, and the observation number (i.e., RW02034).

The plotting section of the program produces a profile of change in the A and B axes from both the initial and the previous set of data, a calibration plot which can show errors in the raw data by plotting the measured difference between A+ and A− and B+ and B−, and a three-dimensional plot of the change in the profile of the hole since the previous date. Figure B-14 shows the three-dimensional plot as an example of one of these CYBER plots. Both velum and microfilm copies of the plots can be produced.

The header contains information on which sets of data have been processed and plotted. Every dam has its own inclinometer header which is updated during each run.

2. **Mail.**—Inclinometer data are also received through the mail. These data must be entered into a file to be processed in the same manner as they would be processed if put directly into CYBER. This is done one of three ways: they may be sent to Keypunch Section, where they type the data into the CYBER; they may be typed directly into a raw file on the CYBER using the editor (XEDIT); or they may be typed into a file using the Hewlett-Packard's editor (EDITOR), and then moved from the SRM to the CYBER to be processed using the DEFLECT program.

B. Entering Data Base

1. **CYBER.**—All the inclinometer data on the CYBER are transferred to the SRM with the HPL program. The first step is to load the CHRMOD program on the H-P and then log on the CYBER. Next, the CYBER program HPL is run, which will ask for the names of the reduced inclinometer files to be transferred. This program will copy the files to the (I:REMOTE) directory on the SRM. Finally, the processor must log off the CYBER and load the INCL-TRANS program on the H-P. This program will convert the ASCII files from the CYBER into numeric data and add this observation to the files for each dam. Each dam has its own directory within the (E/INCL:REMOTE) directory. The tree structure of directories on figure B-5 shows inclinometer files in a separate directory under (E:REMOTE).

The data for inclinometer files are separated from the other data because they are stored differently. There are two files for each hole, one containing data from the A axis and the second file containing data from the B axis. The file structure is the same as other data, yet each variable location contains an incremental depth within each hole. The two files must always contain the same number of variables (depths) and the same number of observations (dates). The labeling convention used on the inclinometer file names is the same as other files with dam abbreviation as the first two characters, the instrument type as the second two, and the remaining characters indicating hole number and an A or B for the axis orientation (e.g., RW02034).

C. Requests of Printouts, Data Corrections, and Plots

1. **INCL START.**—The INCL-START program is used to edit and list the inclinometer data files. The data are stored on two files for each hole so the user must remember to change both files when changing

the number of variables (depth) or observations (date). This program has the same menus and displays as the noninclinometer START program (figure B-10).

2. **INCL PLOT.**—The INCL-PLOT program produces three different plots, PROFILE, SLICE, and MULTIPROFILE. The program plots on the graphics and to the spooler, and can only be run on the HP9845's. Both plots use a header file, which serves three functions. First, it stores the labeling information, hole location, direction of movement, etc. Second, it stores the depths at which the SLICE program is to plot. Lastly, the observation and date of the last plot are stored, so the program can automatically plot all the new data that have been added.

a. **PROFILE.**—This plot gives a cross-section view of the movement of the inclinometer hole. The plot, figure B-15, shows the initial profile and change from initial, in the A-axis and B-axis directions. Two scales are drawn along the bottom axis; the angled numbers scale the absolute deflection of the initial profile, and the other scale shows the movement since that initial installation. Both scales are calculated to expand to the largest deflection found in both axes.

b. **SLICE.**—This program is also called SLICE HISTORY, because it gives an overhead view of the movement of the inclinometer hole at different elevations for all the observations. The reviewer will choose a depth where possibly a shear zone or other movement has occurred. Figure B-16 shows a depth of 9 feet below the collar or an elevation of 16.3 feet. This elevation is sliced open to show the change from the initial survey in both the A and B axes for each observation. The scaling is automatic and will expand to the largest change of all these observations. It will scale the same for every elevation chosen.

c. **MULTIPROFILE.**—This program was written primarily to show the movement of the profile of an inclinometer casing when incremental installations are used. Basically, it is several PROFILE plots superimposed onto one plot. The user can select up to 10 dates to be shown on each plot. The A and B axes are separated into two plots. An example is shown on figure B-17.

III. General Purpose Programs — Utilities

A. Programs

All of these programs are used to perform duties other than data entry or routine plotting. Each has become very important in making the entire data processing procedure as easy and reliable as possible. Figure B-18 is an example of the type of menus used for each of the utilities; in this case, the BACKUP menu is shown.

1. **BACKUP.**—The BACKUP program provides recoverable copies of data and programs, which may have been lost or improperly changed. There are six options within the program, which are presented in menu form. Three of these which are regularly used are: weekly backup, daily backup, and restoring a lost or corrupted file to SRM.

The weekly backup is done on 8-inch disks, which contain a copy of everything under the (E:REMOTE) directory. The file names are stored as numbers on the disks and are matched with their names on the SRM with a list stored in a file. The program reads in this file then catalogs each directory and matches the date of the last modification in all the files with the date of the last backup. Any file newer than the last date is flagged to be backed up. The program will display the disk number, purge the old copy off the disk, and copy the new version. Approximately every 4 months, a new generation of backup is made to provide another version of a file. Three generations of backup are kept.

The daily backup option should be run at the end of every day. The files are copied to a directory on the SRM along with the matching list. The daily option only copies files that have been updated since the last weekly backup. This protects daily work. All daily backup files are purged during a weekly backup to conserve SRM disk space.

The recovery of files option can recover a file from the daily or weekly backup. The program will ask for the file name and whether to look into the daily or weekly backup list. If the weekly is chosen, it will tell the user which disk to insert.

2. **EDITOR.**—This program is used as a word processor or text editor. It has most of the capabilities of other word processors to move, copy, condense, and store text into files on the SRM. These files can be printed on either one of the fast HP2631 dot matrix printers or the letter quality HP2601 daisy wheel printer. EDITOR is used for documentation and correspondence, and can be used to read all files of type ASCII.

3. **LISTALL.**—This program prints files out in the same format as the START program. The advantage of LISTALL is that up to 50 file names may be entered at one time and it will run unattended until they are all printed out, START only lists 1 file at a time.

4. **COPY.**—This program has three options: it will copy files from one directory to another, it will copy files and then purge the files from the source directory, or it will purge files. It will ask for the desired option and the directory. The program will display a sorted list of the files and ask which ones are to be copied and/or purged.

5. **CAT.**—This program will catalog any directory and give a sorted list. It will ask for the type of files that the user wishes to see. The only other option is where to print the listing.

6. **DEBUG.**—This program is used to edit any ASCII data file. There are three options in the program: to delete text, insert text, or list text.

7. **CHARTS/TEXT.**—This program is used to create a variety of bar charts and pie charts for data presentations. It also is used for any type of freehand drawings or charts. Text can be added to any chart in several different font styles. The program uses a digitizer pad with an overlay to create and move text and charts, which can be stored on disk. Figure B-19 shows a pie chart created with this program.

GLOSSARY OF TERMS AND PROGRAMS

ASCII	— Format which data are stored under which allow them to be moved between different computers.
2. AUTO-TIMEPLOT	— H-P program which plots data versus time automatically when new data are entered into the data base.
3. BACKUP	— H-P program which copies data from the hard disk onto floppy disks to protect those data from being lost.
4. CAT	— H-P program that gives a sorted listing of file names.
5. CHRMOD	— H-P program that allows the H-P computers to communicate with other computers.
6. CONTUR	— H-P program that plots contours of data on a drawing.
7. COPY	— H-P program that copies and/or purges data files.
8. CYBER	— Division of Information Resources' mainframe computer used by our branch to receive and reduce field data.
9. DEBUG	— H-P program which is used to edit ASCII data files.
10. DECODE	— CYBER program which deciphers the satellite data file from an automated damsite, to add to the H-P data base.

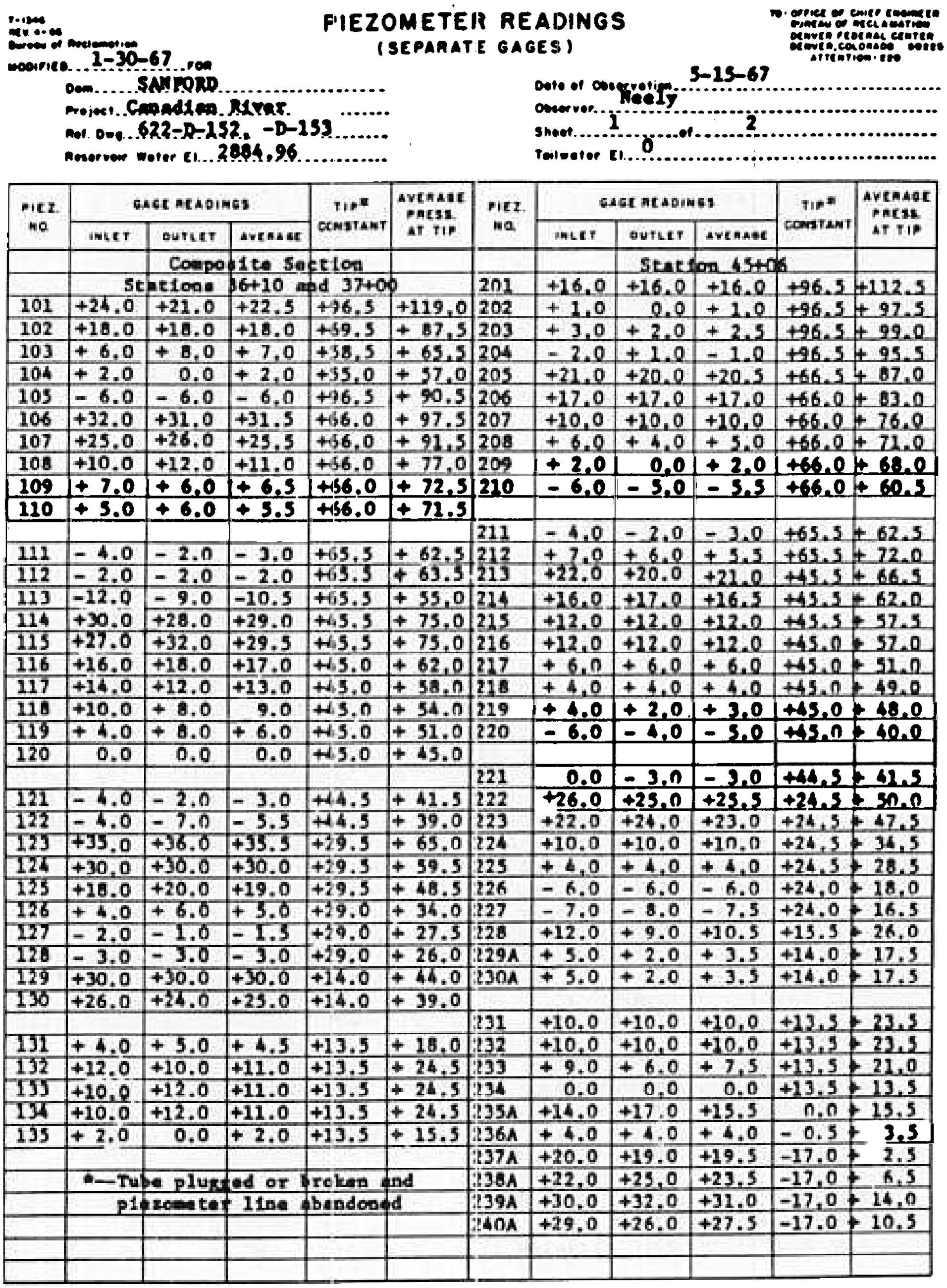
11. DEFLECT — CYBER program that processes and plots inclinometer data.
12. EDITOR — H-P program which is used as a word processor.
13. GO — CYBER program which is used by field personnel to send data to our office which will update the H-P data base.
14. GOES — Geostationary satellite which receives data from a damsite which are then transmitted to a ground station.
15. HPL — CYBER program which sends inclinometer data to the H-P.
16. INCL-PLOT — H-P program which plots inclinometer data three ways: PROFILE, SLICE, and MULTIPROFILE
17. INCL-START — H-P program used to edit or list inclinometer data files.
18. KEEP — CYBER procedure within the GO program that saves the data and routes copies of listings to specified offices.
19. LISTALL — H-P program used to printout the data from several files.
20. MPPLT — H-P program which plots measurement point data relative to their location in a line of points.
21. MULTIPROFILE — H-P routine within INCL-PLOT which plots the profile of an inclinometer hole versus profiles of other dates.
22. PLOT-QUEUE — H-P directory which contains the abbreviation of new data which has been entered so it may be plotted.
23. PROFILE — H-P routine within INCL-PLOT which plots the movement of the profile of an inclinometer hole.
24. SEMLOG — H-P program which plots data versus semilog time.
25. SENDALL — CYBER program which sends data from the CYBER to the H-P.
26. SLICE — H-P routine within INCL-PLOT which plots the movement of an elevation of an inclinometer hole over time.
27. START — H-P program used to edit and printout data files.
28. SRM — Shared Resource Manager controls all the files stored in the H-P data base and their printing and plotting.
29. TELXON — A hand-held computer used for data entry in the field which transmits that data over CYBER.
30. TEXT/CHARTS — H-P program used to display text and or plot data on charts not routinely plotted with other programs.
31. TIMEPLOT — H-P program which plots data versus time.
32. UPCHUK — H-P program which moves data from the CYBER into their correct files in the data base on the H-P.
33. UPDATE — H-P program which data entry personnel use to input data received by mail into our data base.
34. XEDIT — CYBER procedure used for editing programs and files.
35. XPLOT — H-P program used to plot one or more variables in a file versus another variable.
36. ZCOLLEC — CYBER file which contains all the data entered into the GO program that need to be brought over to the H-P.

```
 PLEASE ENTER DATA FILE NAME (TO EXIT HIT "CR")
? RFTELX

 PLEASE ENTER DAM NAME
? RED FLEET

 PLEASE ENTER OBSERVER
? HUGHES

 PLEASE ENTER RECORDER
? SMITH

 PLEASE ENTER DATE
 ENTER MMDDYY
? 070886

ENTER RESERVOIR ELEVATION ("CR" IF NONE)
? 5605.2

ENTER TAILWATER ELEVATION ("CR" IF NONE)
? 5510.6

 DO YOU NEED INSTRUCTIONS  I.E. Y OR N)
? N

DO YOU WISH PROMPTING WITH INSTRUMENT LABELS (Y/N)?
? Y

SPECIAL COMMANDS ...
EDIT ... EDITS THE PREVIOUS LABEL OR READING
TYPE ... CHANGES TO A NEW INSTRUMENT TYPE
END  ... ENDS THE ENTRY OF LABELS AND READINGS
"CR" ... SKIPS A LABEL (RECORDS "NOT READ")

DO YOU WISH INSTRUMENT TYPE  (GP)  (Y/N)?
? Y

 ENTER THE READING FOR GP-101
? 10.2

 ENTER THE READING FOR GP-102
? 14.5

 ENTER THE READING FOR GP-103
? 4.6

 ENTER THE READING FOR GP-105
? TYPE

DO YOU WISH INSTRUMENT TYPE  (HD)  (Y/N)?
? N

ENTER COMMENTS (30 CHARS. PER LINE) ... (E) TO END
? THIS IS TEST DATA              *
? E

RFTELX  HAS BEEN SAVED AND IS READY TO PROCESS ... 5   PROCESS FIELD READINGS
```

Figure B-1

```
   THE OPTIONS FOR THIS PROGRAM ARE

        PERFORM SET MAINTENANCE

    2 - UPDATE THE MASTER DATA FILE

    3 - TRANSMIT PREVIOUS TO TELXON

    4 - ENTER FIELD READINGS

    5   PROCESS THE FIELD READINGS

    6   INITIATE THE KEEP PROCESS

        EXIT FROM THIS PROGRAM


ENTER YOUR SELECTION? 5

ENTER THE NAME OF THE FIELD READINGS FILE ? RFTELX
SET UP THE PRINTER AND HIT CARRIAGE RETURN
?

                 WATER LEVEL MEASUREMENTS IN PNEUMATIC PIEZOMETERS

                                      LOCATION:  RED FLEET
                                          DATE:  07/08/86
 RESERVOIR WATER SURFACE              5605.20    TAILWATER ELEVATION               5510.60
 PREVIOUS ELEVATION    061986         5607.62    PREVIOUS ELEVATION                5512.00

 OBSERVER: HUGHES                                RECORDER: SMITH

  OBSERV.       ELEV.   READING  INITIAL  PREVIOUS  CURRENT  CHANGE     DATE   CHANGE
  WELL OR    PIEZOMETER   IN      ELEV.     ELEV.    ELEV.    FROM       OF     FROM
 PIEZOMETER     TIP       PSI   OF WATER  OF WATER OF WATER  PREV       PREV   INITIAL
   NO.                                                       READING  READING


 GP-101       5529.4     10.2    5531.0    5531.2   5552.9    21.7    061986   21.9

 GP-102       5506.0     14.5    5507.4    5506.9   5539.4    32.5    061986   32.0

 GP-103       5532.8      4.6    5534.3    5536.3   5543.4     7.2    061986    9.1

 GP-104       5472.1      5.6    5484.4    5514.3   5485.0   -29.3    061986     .6

 GP-105       5530.3   NOT READ  5530.6    5531.0                     061986

 GP-106       5470.8   NOT READ  5488.8    5504.0                     061986
```

Figure B-2



7-1346
REV. 4-66
Bureau of Reclamation
MODIFIED 1-30-67 FOR

PIEZOMETER READINGS
(SEPARATE GAGES)

TO: OFFICE OF CHIEF ENGINEER
BUREAU OF RECLAMATION
DENVER FEDERAL CENTER
DENVER, COLORADO 80225
ATTENTION: 220

Dam SANFORD
Project Canadian River
Ref. Dwg. 622-D-152, -D-153
Reservoir Water El. 2884.96

Date of Observation 5-15-67
Observer Neely
Sheet 1 of 2
Tailwater El. 0

PIEZ. NO.	GAGE READINGS			TIP* CONSTANT	AVERAGE PRESS. AT TIP	PIEZ. NO.	GAGE READINGS			TIP* CONSTANT	AVERAGE PRESS. AT TIP
	INLET	OUTLET	AVERAGE				INLET	OUTLET	AVERAGE		
		Composite Section						Station 45+06			
	Stations 36+10 and 37+00					201	+16.0	+16.0	+16.0	+96.5	+112.5
101	+24.0	+21.0	+22.5	+96.5	+119.0	202	+ 1.0	0.0	+ 1.0	+96.5	+ 97.5
102	+18.0	+18.0	+18.0	+69.5	+ 87.5	203	+ 3.0	+ 2.0	+ 2.5	+96.5	+ 99.0
103	+ 6.0	+ 8.0	+ 7.0	+58.5	+ 65.5	204	- 2.0	+ 1.0	- 1.0	+96.5	+ 95.5
104	+ 2.0	0.0	+ 2.0	+55.0	+ 57.0	205	+21.0	+20.0	+20.5	+66.5	+ 87.0
105	- 6.0	- 6.0	- 6.0	+96.5	+ 90.5	206	+17.0	+17.0	+17.0	+66.0	+ 83.0
106	+32.0	+31.0	+31.5	+66.0	+ 97.5	207	+10.0	+10.0	+10.0	+66.0	+ 76.0
107	+25.0	+26.0	+25.5	+66.0	+ 91.5	208	+ 6.0	+ 4.0	+ 5.0	+66.0	+ 71.0
108	+10.0	+12.0	+11.0	+66.0	+ 77.0	209	+ 2.0	0.0	+ 2.0	+66.0	+ 68.0
109	+ 7.0	+ 6.0	+ 6.5	+56.0	+ 72.5	210	- 6.0	- 5.0	- 5.5	+66.0	+ 60.5
110	+ 5.0	+ 6.0	+ 5.5	+56.0	+ 71.5						
						211	- 4.0	- 2.0	- 3.0	+65.5	+ 62.5
111	- 4.0	- 2.0	- 3.0	+65.5	+ 62.5	212	+ 7.0	+ 6.0	+ 5.5	+65.5	+ 72.0
112	- 2.0	- 2.0	- 2.0	+65.5	+ 63.5	213	+22.0	+20.0	+21.0	+45.5	+ 66.5
113	-12.0	- 9.0	-10.5	+65.5	+ 55.0	214	+16.0	+17.0	+16.5	+45.5	+ 62.0
114	+30.0	+28.0	+29.0	+45.5	+ 75.0	215	+12.0	+12.0	+12.0	+45.5	+ 57.5
115	+27.0	+32.0	+29.5	+45.5	+ 75.0	216	+12.0	+12.0	+12.0	+45.0	+ 57.0
116	+16.0	+18.0	+17.0	+45.0	+ 62.0	217	+ 6.0	+ 6.0	+ 6.0	+45.0	+ 51.0
117	+14.0	+12.0	+13.0	+45.0	+ 58.0	218	+ 4.0	+ 4.0	+ 4.0	+45.0	+ 49.0
118	+10.0	+ 8.0	9.0	+45.0	+ 54.0	219	+ 4.0	+ 2.0	+ 3.0	+45.0	+ 48.0
119	+ 4.0	+ 8.0	+ 6.0	+45.0	+ 51.0	220	- 6.0	- 4.0	- 5.0	+45.0	+ 40.0
120	0.0	0.0	0.0	+45.0	+ 45.0						
						221	0.0	- 3.0	- 3.0	+44.5	+ 41.5
121	- 4.0	- 2.0	- 3.0	+44.5	+ 41.5	222	+26.0	+25.0	+25.5	+24.5	+ 50.0
122	- 4.0	- 7.0	- 5.5	+44.5	+ 39.0	223	+22.0	+24.0	+23.0	+24.5	+ 47.5
123	+35.0	+36.0	+35.5	+29.5	+ 65.0	224	+10.0	+10.0	+10.0	+24.5	+ 34.5
124	+30.0	+30.0	+30.0	+29.5	+ 59.5	225	+ 4.0	+ 4.0	+ 4.0	+24.5	+ 28.5
125	+18.0	+20.0	+19.0	+29.5	+ 48.5	226	- 6.0	- 6.0	- 6.0	+24.0	+ 18.0
126	+ 4.0	+ 6.0	+ 5.0	+29.0	+ 34.0	227	- 7.0	- 8.0	- 7.5	+24.0	+ 16.5
127	- 2.0	- 1.0	- 1.5	+29.0	+ 27.5	228	+12.0	+ 9.0	+10.5	+15.5	+ 26.0
128	- 3.0	- 3.0	- 3.0	+29.0	+ 26.0	229A	+ 5.0	+ 2.0	+ 3.5	+14.0	+ 17.5
129	+30.0	+30.0	+30.0	+14.0	+ 44.0	230A	+ 5.0	+ 2.0	+ 3.5	+14.0	+ 17.5
130	+26.0	+24.0	+25.0	+14.0	+ 39.0						
						231	+10.0	+10.0	+10.0	+13.5	+ 23.5
131	+ 4.0	+ 5.0	+ 4.5	+13.5	+ 18.0	232	+10.0	+10.0	+10.0	+13.5	+ 23.5
132	+12.0	+10.0	+11.0	+13.5	+ 24.5	233	+ 9.0	+ 6.0	+ 7.5	+13.5	+ 21.0
133	+10.0	+12.0	+11.0	+13.5	+ 24.5	234	0.0	0.0	0.0	+13.5	+ 13.5
134	+10.0	+12.0	+11.0	+13.5	+ 24.5	235A	+14.0	+17.0	+15.5	0.0	+ 15.5
135	+ 2.0	0.0	+ 2.0	+13.5	+ 15.5	236A	+ 4.0	+ 4.0	+ 4.0	- 0.5	+ 3.5
						237A	+20.0	+19.0	+19.5	-17.0	+ 2.5
	*—Tube plugged or broken and					238A	+22.0	+25.0	+23.5	-17.0	+ 6.5
	piezometer line abandoned					239A	+30.0	+32.0	+31.0	-17.0	+ 14.0
						240A	+29.0	+26.0	+27.5	-17.0	+ 10.5

Figure B-3

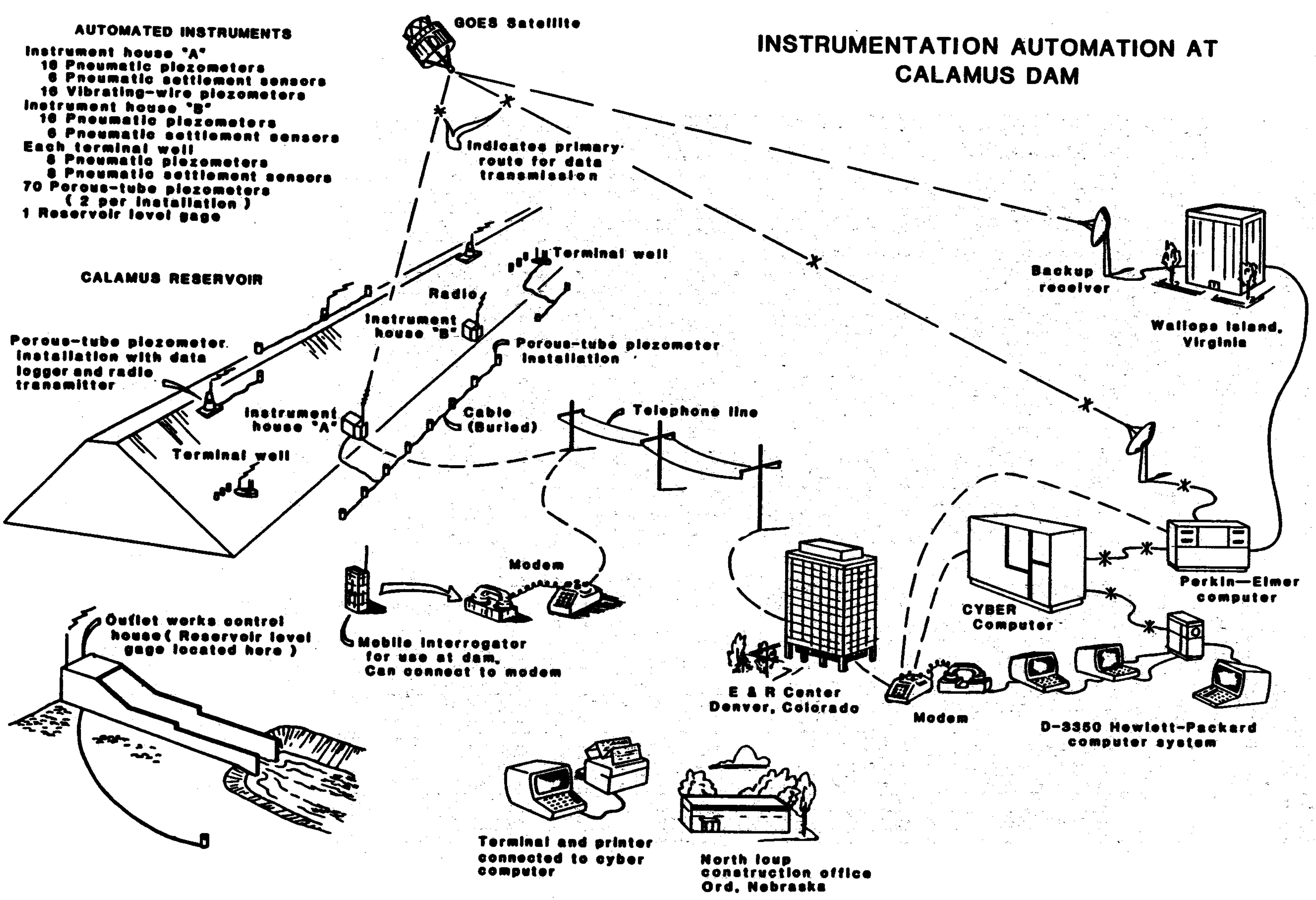
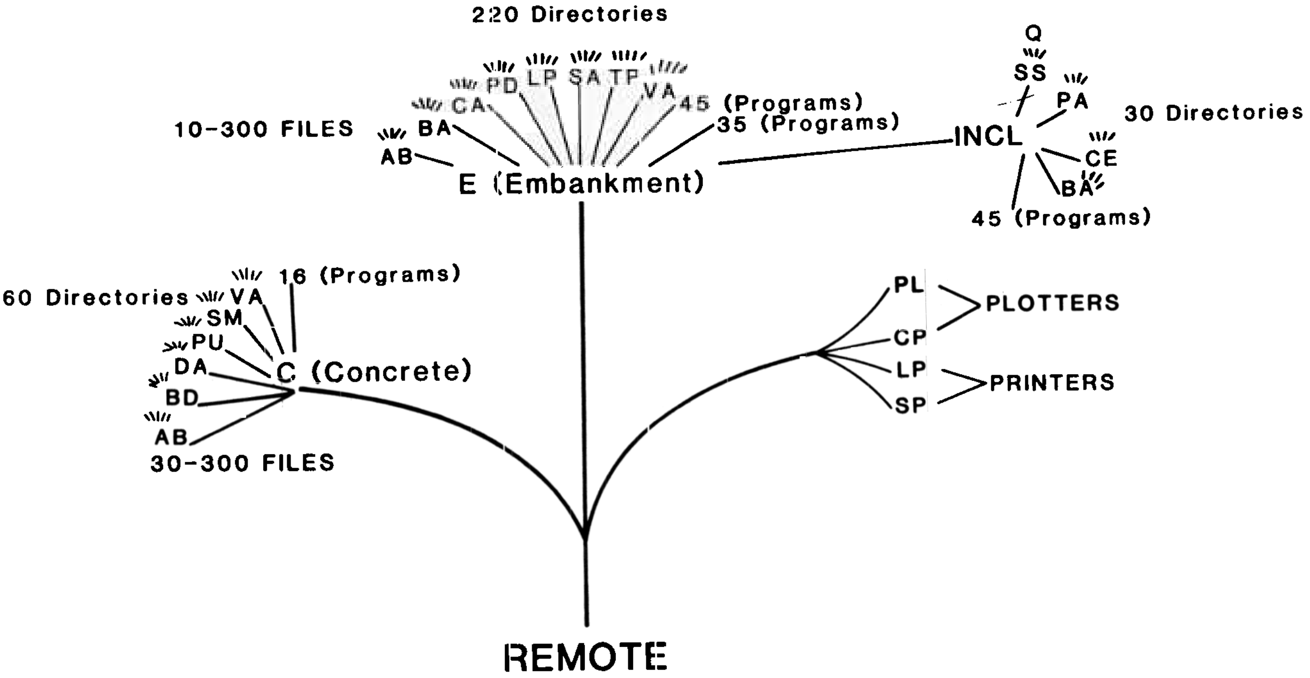
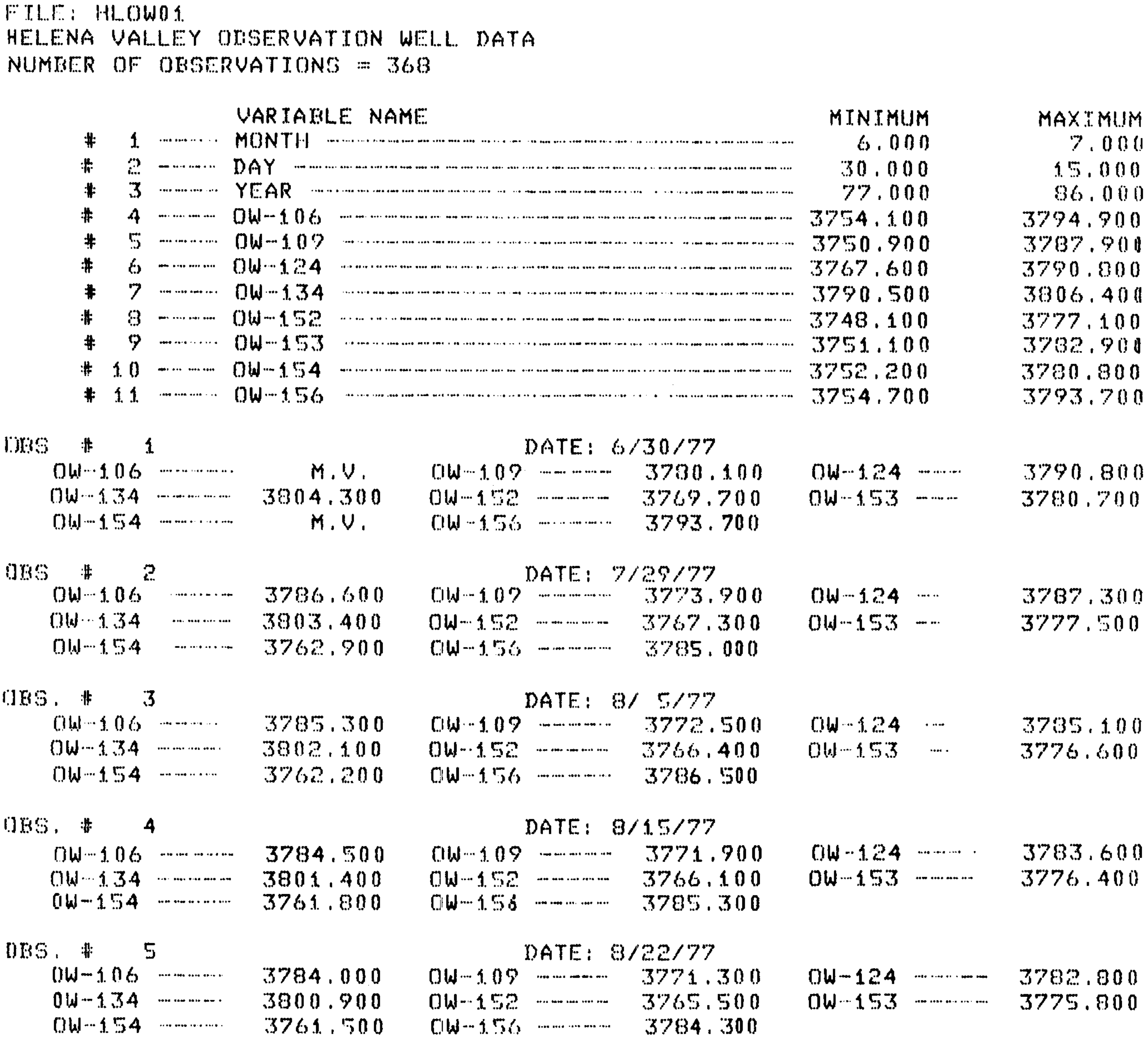
INSTRUMENTATION AUTOMATION AT CALAMUS DAM
AUTOMATED INSTRUMENTS
Instrument house 'A'
16 Pneumatic piezometers
6 Pneumatic settlement sensors
16 Vibrating-wire piezometers
Instrument house 'B'
16 Pneumatic piezometers
6 Pneumatic settlement sensors
Each terminal well
8 Pneumatic piezometers
8 Pneumatic settlement sensors
70 Porous-tube piezometers
(2 per installation)
1 Reservoir level gage
GOES Satellite
Indicates primary route for data transmission
CALAMUS RESERVOIR
Terminal well
Radio
Instrument house 'B'
Porous-tube piezometer installation with data logger and radio transmitter
Porous-tube piezometer installation
Instrument house 'A'
Cable (Buried)
Telephone line
Terminal well
Backup receiver
Wallops Island, Virginia
Modem
Perkin—Elmer computer
CYBER Computer
Outlet works control house (Reservoir level gage located here)
Mobile interrogator for use at dam, Can connect to modem
E & R Center Denver, Colorado
Modem
D-3350 Hewlett-Packard computer system
Terminal and printer connected to cyber computer
North loup construction office Ord, Nebraska

Figure B-4



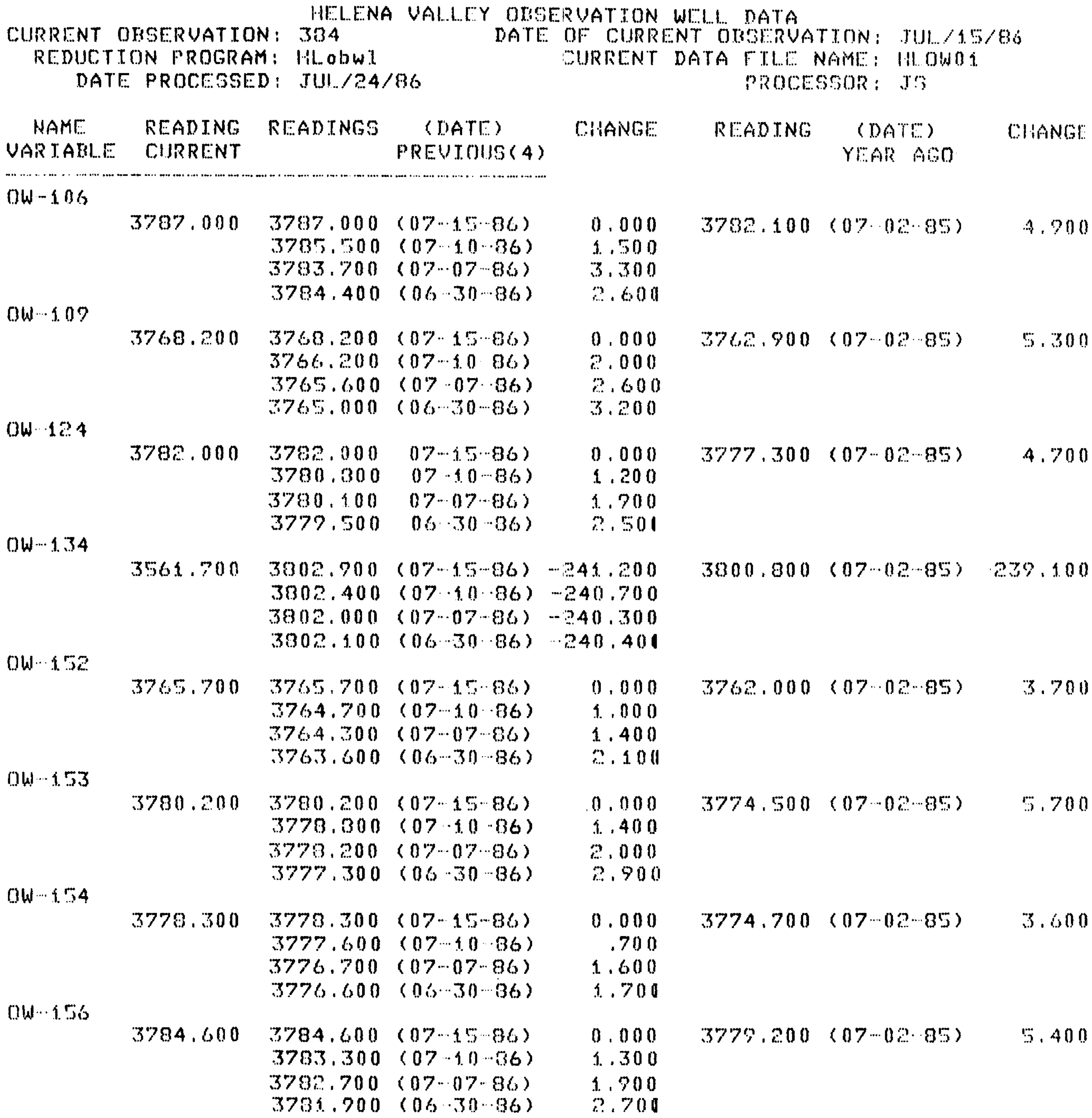
DATA BASE
FILE STRUCTURE

Figure B-5



```
FILE: HLOW01
HELENA VALLEY OBSERVATION WELL DATA
NUMBER OF OBSERVATIONS = 368

                 VARIABLE NAME                                      MINIMUM        MAXIMUM
     #  1 ------ MONTH ----------------------------------------      6.000          7.000
     #  2 ------ DAY ------------------------------------------     30.000         15.000
     #  3 ------ YEAR -----------------------------------------     77.000         86.000
     #  4 ------ OW-106 ---------------------------------------   3754.100       3794.900
     #  5 ------ OW-109 ---------------------------------------   3750.900       3787.900
     #  6 ------ OW-124 ---------------------------------------   3767.600       3790.800
     #  7 ------ OW-134 ---------------------------------------   3790.500       3806.400
     #  8 ------ OW-152 ---------------------------------------   3748.100       3777.100
     #  9 ------ OW-153 ---------------------------------------   3751.100       3782.900
     # 10 ------ OW-154 ---------------------------------------   3752.200       3780.800
     # 11 ------ OW-156 ---------------------------------------   3754.700       3793.700

OBS  #    1                          DATE: 6/30/77
   OW-106 -------      M.V.     OW-109 ------   3780.100    OW-124 ----     3790.800
   OW-134 ------   3804.300     OW-152 ------   3769.700    OW-153 ---      3780.700
   OW-154 -------      M.V.     OW-156 ------   3793.700

OBS  #    2                          DATE: 7/29/77
   OW-106  ------  3786.600     OW-109 ------   3773.900    OW-124 --       3787.300
   OW-134  ------  3803.400     OW-152 ------   3767.300    OW-153 --       3777.500
   OW-154  ------  3762.900     OW-156 ------   3785.000

OBS. #    3                          DATE: 8/ 5/77
   OW-106 -----    3785.300     OW-109 ------   3772.500    OW-124  --      3785.100
   OW-134 ------   3802.100     OW-152 ------   3766.400    OW-153  --      3776.600
   OW-154 -----    3762.200     OW-156 ------   3786.500

OBS. #    4                          DATE: 8/15/77
   OW-106 -------  3784.500     OW-109 ------   3771.900    OW-124 -----    3783.600
   OW-134 -------  3801.400     OW-152 ------   3766.100    OW-153 ------   3776.400
   OW-154 -------  3761.800     OW-156 ------   3785.300

OBS. #    5                          DATE: 8/22/77
   OW-106 ------   3784.000     OW-109 ------   3771.300    OW-124 -------  3782.800
   OW-134 ------   3800.900     OW-152 ------   3765.500    OW-153 -------  3775.800
   OW-154 ------   3761.500     OW-156 ------   3784.300
```

Figure B-6



```
                    HELENA VALLEY OBSERVATION WELL DATA
CURRENT OBSERVATION: 384          DATE OF CURRENT OBSERVATION: JUL/15/86
  REDUCTION PROGRAM: HLobwl             CURRENT DATA FILE NAME: HLOW01
     DATE PROCESSED: JUL/24/86                      PROCESSOR: JS

  NAME      READING  READINGS   (DATE)     CHANGE     READING   (DATE)      CHANGE
VARIABLE    CURRENT            PREVIOUS(4)                      YEAR AGO
-----------------------------------------------------------------
OW-106
          3787.000  3787.000 (07-15-86)    0.000    3782.100 (07-02-85)     4.900
                    3785.500 (07-10-86)    1.500
                    3783.700 (07-07-86)    3.300
                    3784.400 (06-30-86)    2.600
OW-109
          3768.200  3768.200 (07-15-86)    0.000    3762.900 (07-02-85)     5.300
                    3766.200 (07-10-86)    2.000
                    3765.600 (07-07-86)    2.600
                    3765.000 (06-30-86)    3.200
OW-124
          3782.000  3782.000  07-15-86)    0.000    3777.300 (07-02-85)     4.700
                    3780.800  07-10-86)    1.200
                    3780.100  07-07-86)    1.900
                    3779.500  06-30-86)    2.500
OW-134
          3561.700  3802.900 (07-15-86) -241.200    3800.800 (07-02-85) -239.100
                    3802.400 (07-10-86) -240.700
                    3802.000 (07-07-86) -240.300
                    3802.100 (06-30-86) -240.400
OW-152
          3765.700  3765.700 (07-15-86)    0.000    3762.000 (07-02-85)     3.700
                    3764.700 (07-10-86)    1.000
                    3764.300 (07-07-86)    1.400
                    3763.600 (06-30-86)    2.100
OW-153
          3780.200  3780.200 (07-15-86)    0.000    3774.500 (07-02-85)     5.700
                    3778.800 (07-10-86)    1.400
                    3778.200 (07-07-86)    2.000
                    3777.300 (06-30-86)    2.900
OW-154
          3778.300  3778.300 (07-15-86)    0.000    3774.700 (07-02-85)     3.600
                    3777.600 (07-10-86)     .700
                    3776.700 (07-07-86)    1.600
                    3776.600 (06-30-86)    1.700
OW-156
          3784.600  3784.600 (07-15-86)    0.000    3779.200 (07-02-85)     5.400
                    3783.300 (07-10-86)    1.300
                    3782.700 (07-07-86)    1.900
                    3781.900 (06-30-86)    2.700
```

Figure B-7

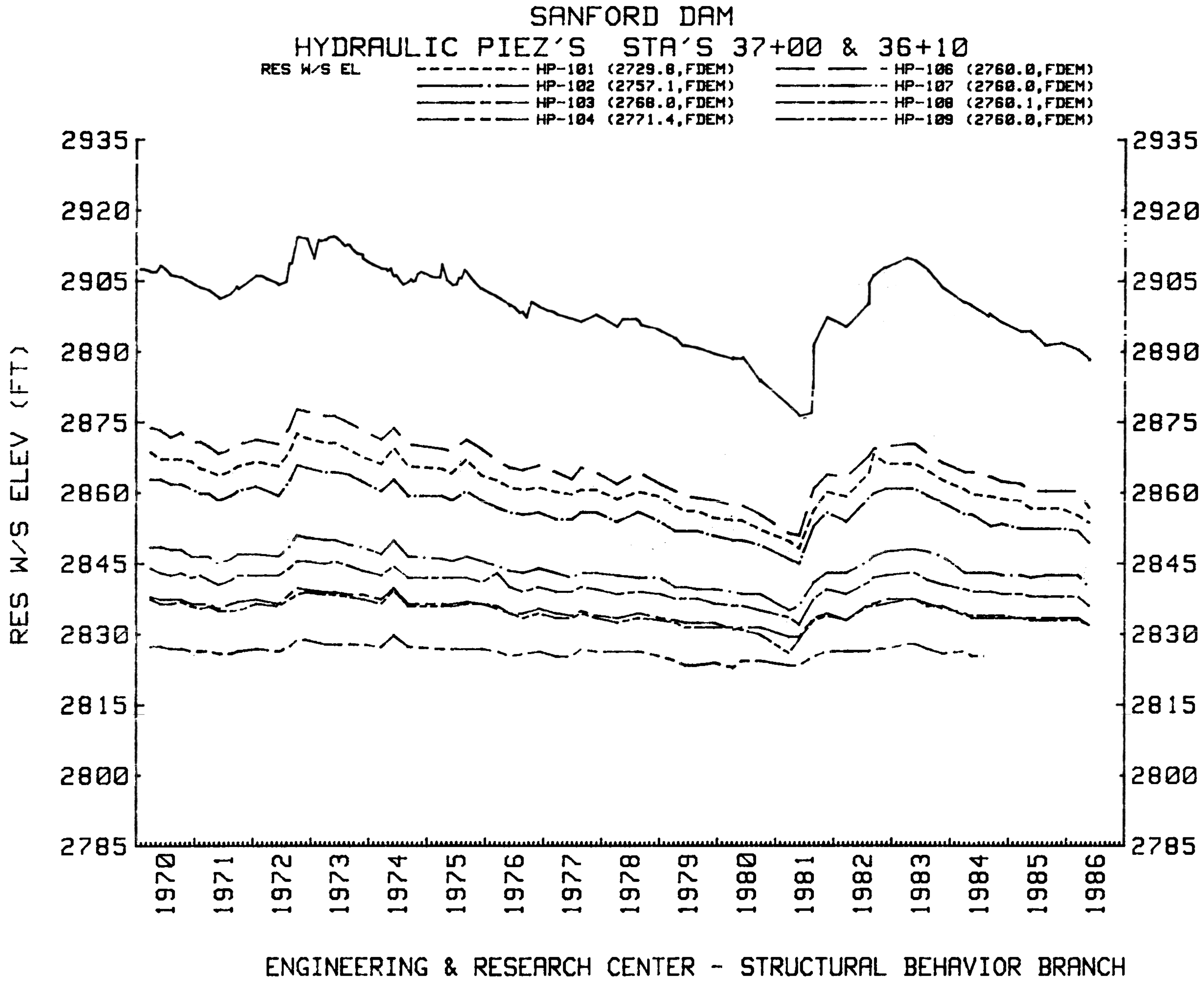

SANFORD DAM
HYDRAULIC PIEZ'S STA'S 37+00 & 36+10
RES W/S EL
HP-101 (2729.8,FDEM)
HP-102 (2757.1,FDEM)
HP-103 (2768.0,FDEM)
HP-104 (2771.4,FDEM)
HP-106 (2760.0,FDEM)
HP-107 (2760.0,FDEM)
HP-108 (2760.1,FDEM)
HP-109 (2760.0,FDEM)
RES W/S ELEV (FT)
PIEZ W/S ELEV (FT)
2935
2920
2905
2890
2875
2860
2845
2830
2815
2800
2785
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
ENGINEERING & RESEARCH CENTER - STRUCTURAL BEHAVIOR BRANCH

Figure B-8

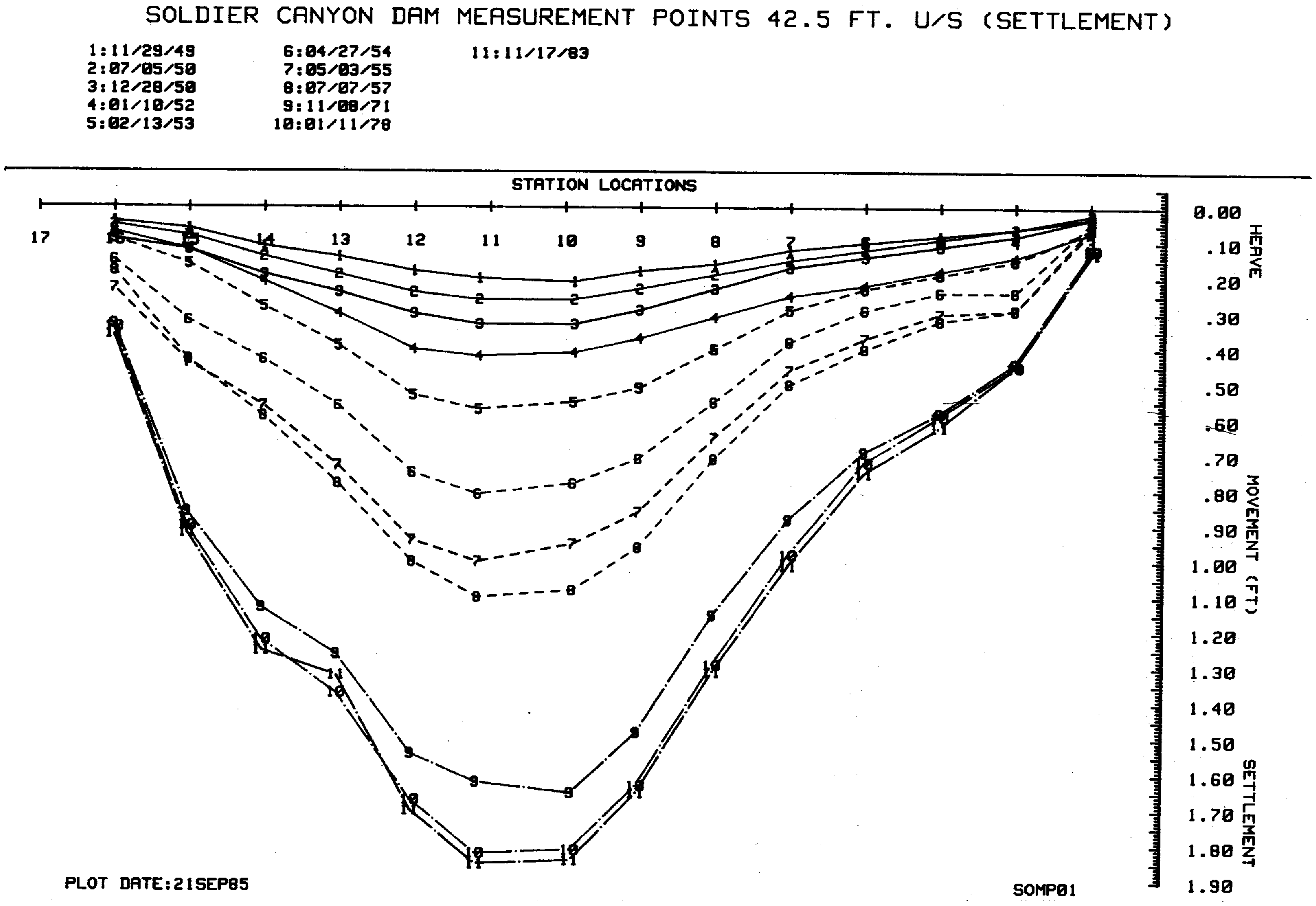
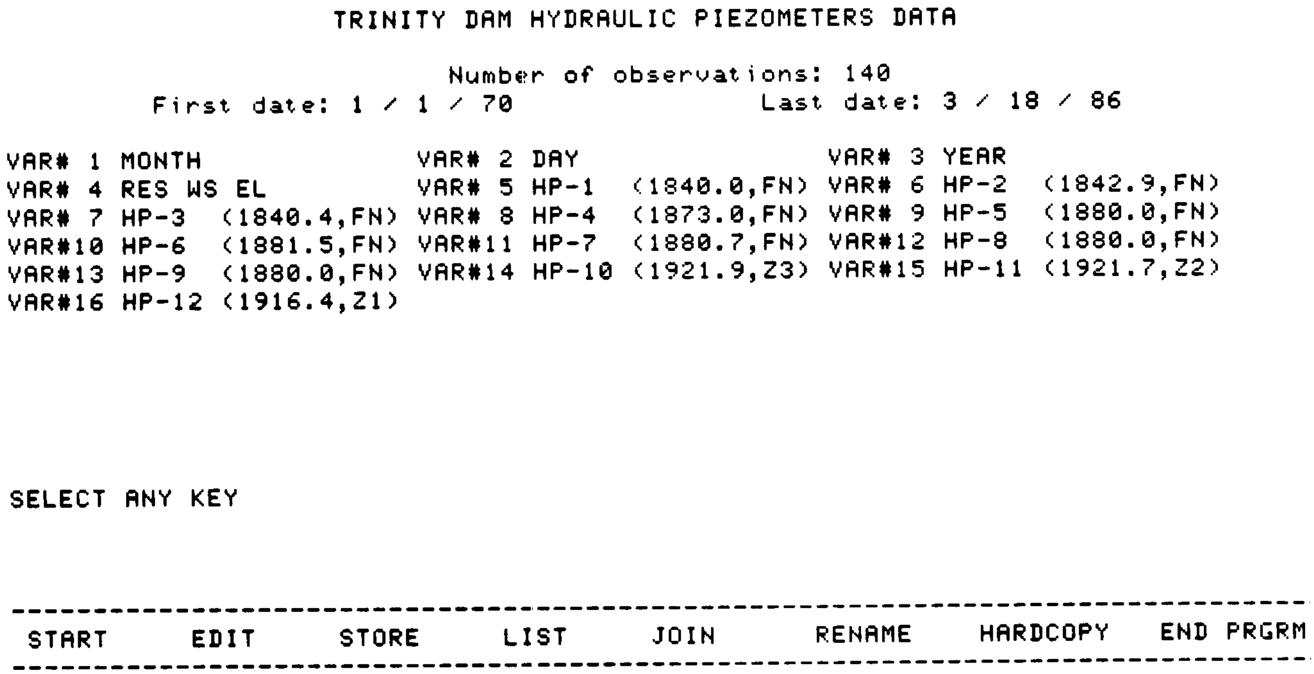

SOLDIER CANYON DAM MEASUREMENT POINTS 42.5 FT. U/S (SETTLEMENT)
1:11/29/49
2:07/05/50
3:12/28/50
4:01/10/52
5:02/13/53
6:04/27/54
7:05/03/55
8:07/07/57
9:11/08/71
10:01/11/78
11:11/17/83
STATION LOCATIONS
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
0.00
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00
1.10
1.20
1.30
1.40
1.50
1.60
1.70
1.80
1.90
HEAVE
MOVEMENT (FT)
SETTLEMENT
PLOT DATE:21SEP85
SOMP01

Figure B-9



```
                    TRINITY DAM HYDRAULIC PIEZOMETERS DATA

                              Number of observations: 140
        First date: 1 / 1 / 70                   Last date: 3 / 18 / 86

VAR# 1 MONTH                VAR# 2 DAY                   VAR# 3 YEAR
VAR# 4 RES WS EL            VAR# 5 HP-1   (1840.0,FN) VAR# 6 HP-2   (1842.9,FN)
VAR# 7 HP-3  (1840.4,FN) VAR# 8 HP-4   (1873.0,FN) VAR# 9 HP-5   (1880.0,FN)
VAR#10 HP-6  (1881.5,FN) VAR#11 HP-7   (1880.7,FN) VAR#12 HP-8   (1880.0,FN)
VAR#13 HP-9  (1880.0,FN) VAR#14 HP-10 (1921.9,Z3) VAR#15 HP-11 (1921.7,Z2)
VAR#16 HP-12 (1916.4,Z1)




SELECT ANY KEY


--------------------------------------------------------------------------------
 START     EDIT      STORE     LIST      JOIN      RENAME     HARDCOPY   END PRGRM
--------------------------------------------------------------------------------
```

Figure B-10

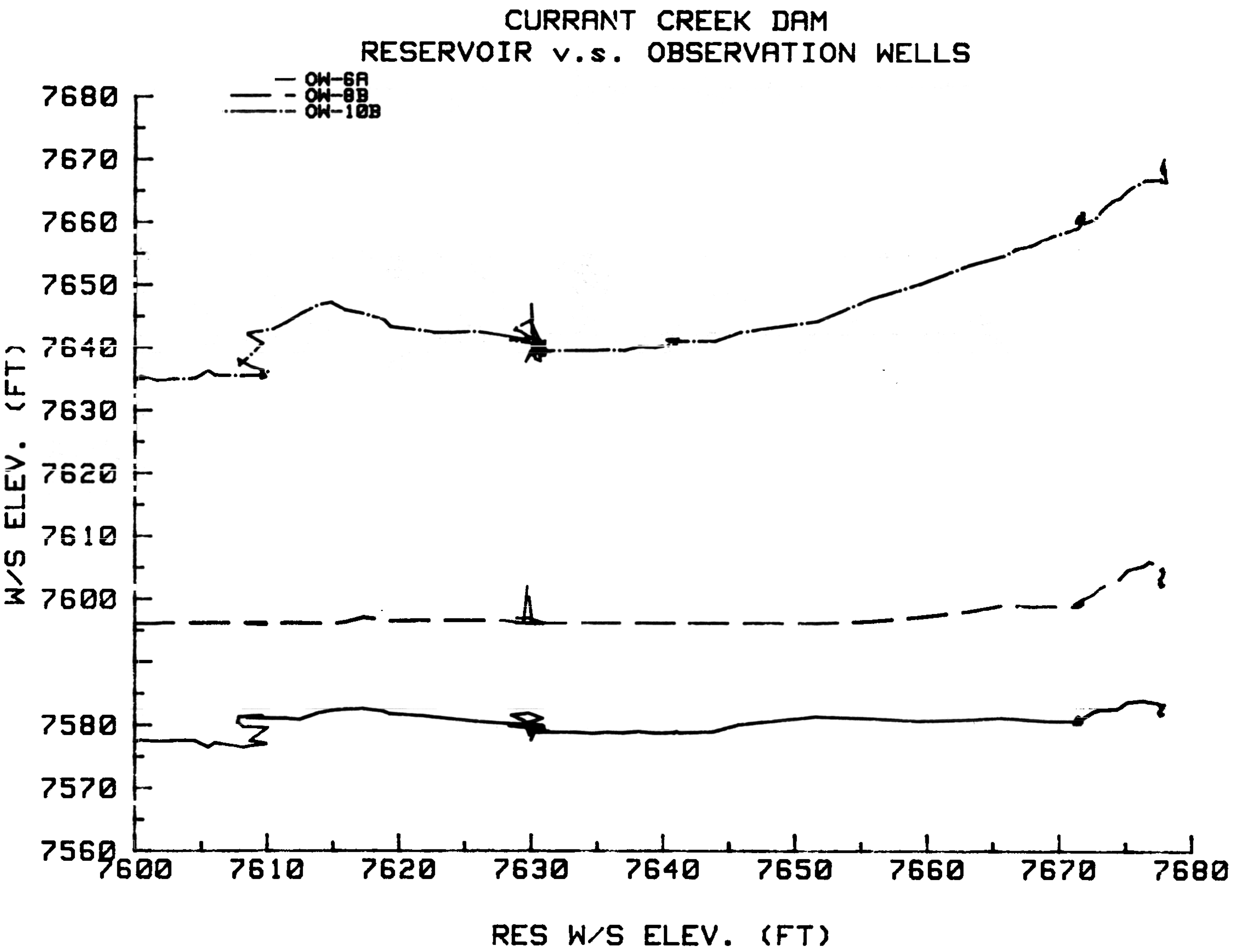


Figure no: CEXPLOTL

Figure B-11

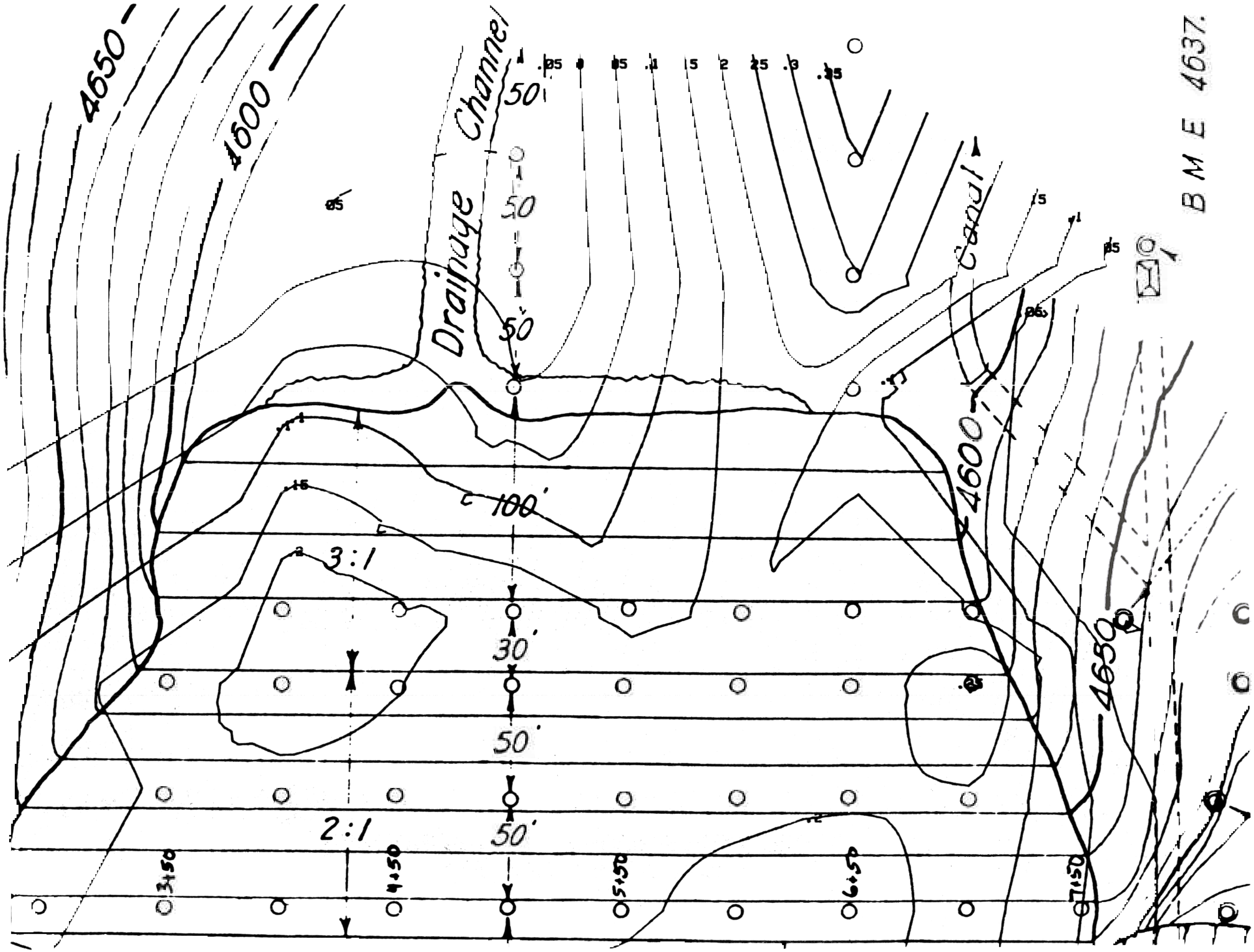

4650
4600
Drainage Channel
Canal
B M E 4637.
50'
50
100'
30'
50'
3:1
2:1
3+50
4+50
5+50
6+50
7+50
.05
.1
.15
.2
.25
.3
.35

Figure B-

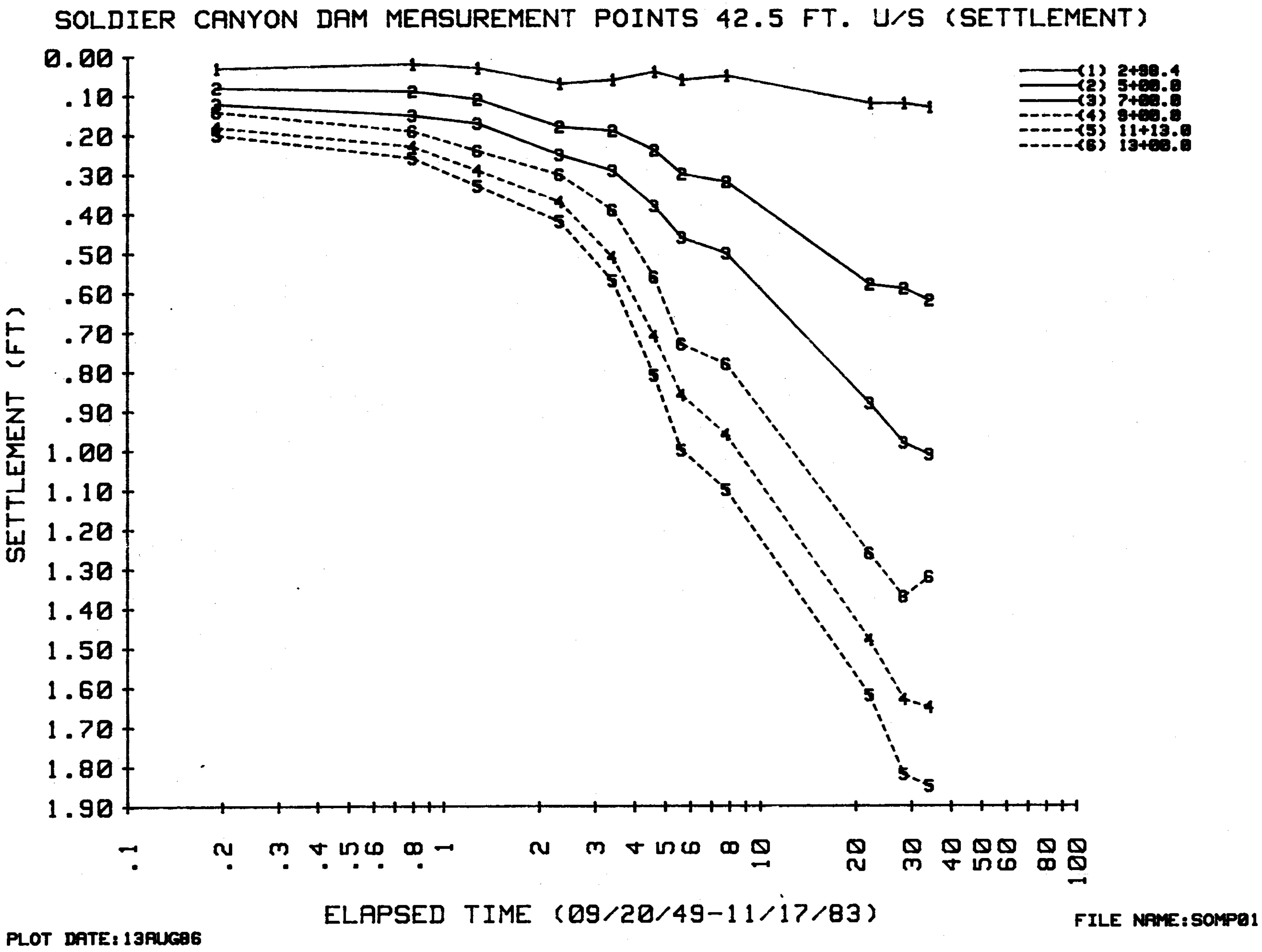
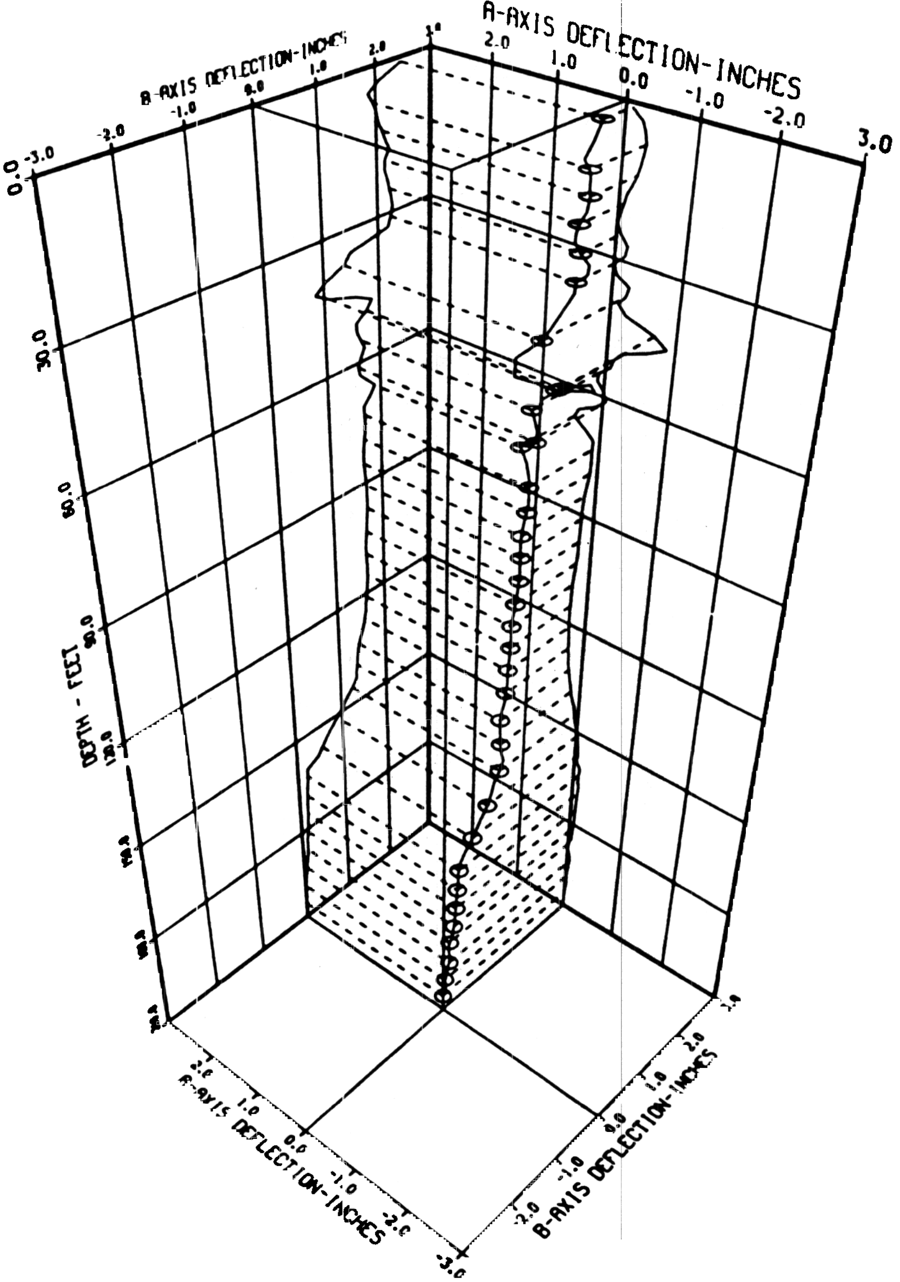

SOLDIER CANYON DAM MEASUREMENT POINTS 42.5 FT. U/S (SETTLEMENT)
SETTLEMENT (FT)
0.00
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00
1.10
1.20
1.30
1.40
1.50
1.60
1.70
1.80
1.90
.1
.2
.3
.4
.5
.6
.8
1
2
3
4
5
6
8
10
20
30
40
50
60
80
100
ELAPSED TIME (09/20/49-11/17/83)
(1) 2+98.4
(2) 5+00.0
(3) 7+00.0
(4) 9+00.0
(5) 11+13.0
(6) 13+00.0
1
2
3
4
5
6
PLOT DATE:13AUG86
FILE NAME:SOMP01

Figure B-13

DALLAS CREEK PROJECT

RIDGWAY DAM

HOLE NO I-3
INCLINOMETER READINGS DATED 02-26-86
FROM SET OF READINGS, SET NO. 127



PLOT 3 10.50.26 TUES 15 APR, 1986 JOB-ABSU , BUREAU OF RECLAMATION DISSPLA 9.2

TEMP297

Figure B-14

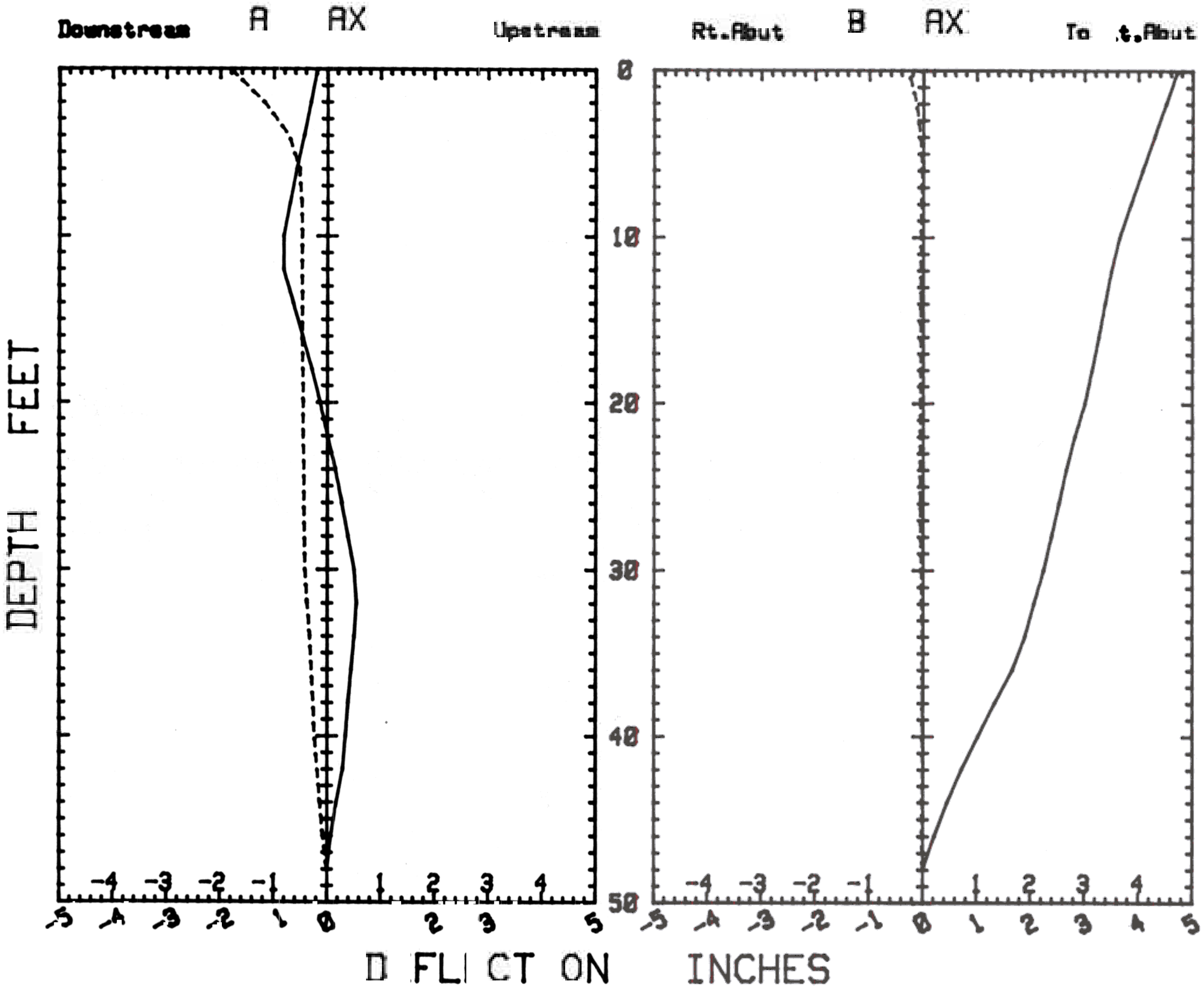
PALMETTO BEND PROJECT
PALMETTO BEND DAM

HOLE #0 OB # 3

Location D/S Crest

Co ar E ev 2 3

n t 1 P f 1 D t 1 /1 /79
Ch g F n t 0 /2 /86



Figure

SLICE HISTORY

DEPTH = 9 FT PALMETTO BEND DAM HOLE 01

ELEV = 16.3 D/S Crest I 1

OB. #	INIT.	1	3	5	7	9	10	11	12	13
A-AX.	-.017	-.017	-.066	-.921	-1.122	-1.231	-1.445	-1.220	-1.206	-1.209
B-AX.	3.656	3.656	3.611	3.589	3.607	3.483	3.629	3.634	3.634	3.619
CH. A	-	0	-.049	-.104	-.305	-.414	-.620	-.411	-.469	-.472
CH. B	-	0	-.045	-.067	-.049	-.173	-.027	-.022	-.022	-.037
DATE	12/17/79	12/17/79	07/03/80	09/04/81	12/08/83	05/23/85	12/05/85	03/20/86	07/02/86	07/28/86

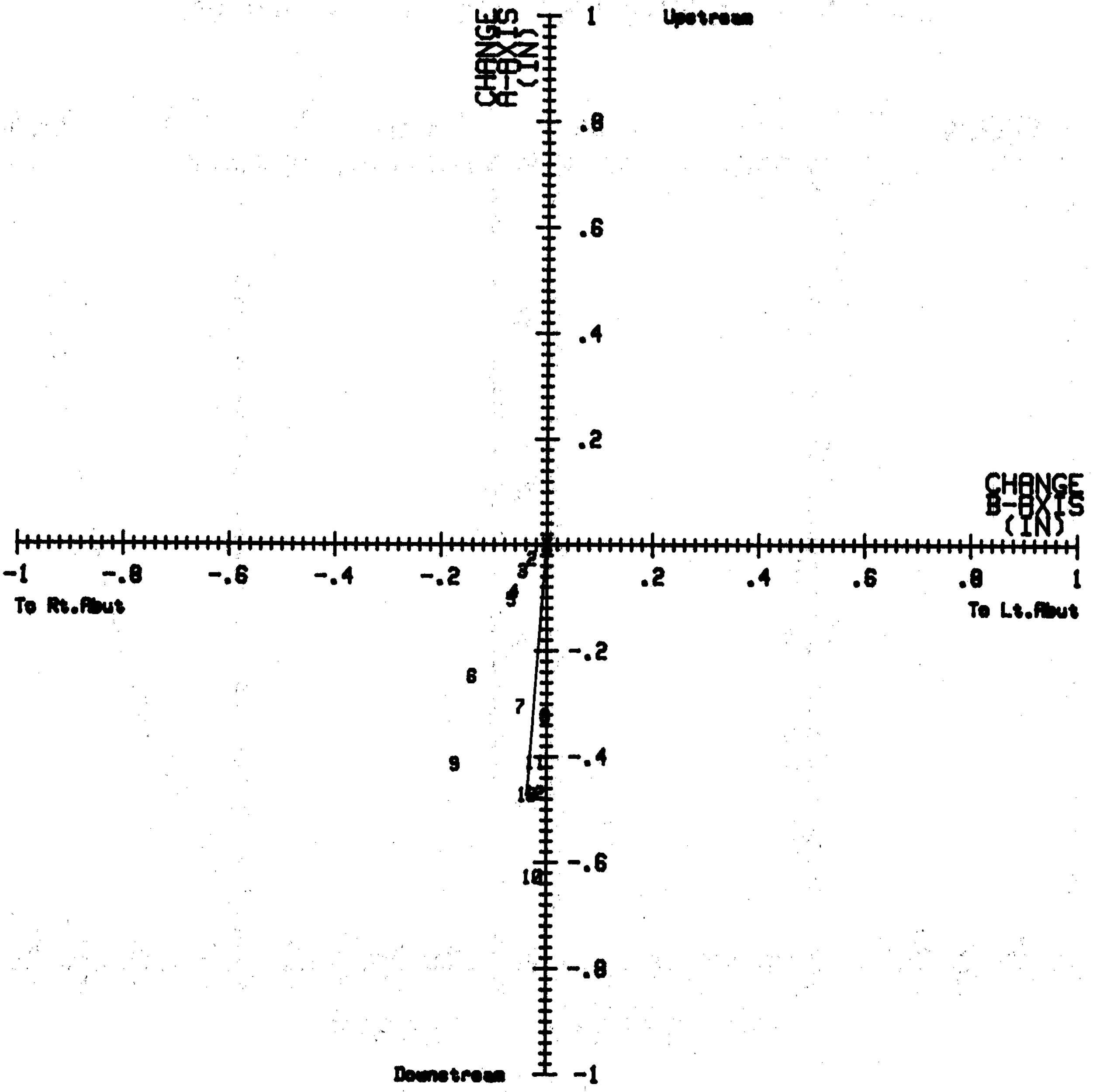


Figure B-16

PALMETTO BEND PROJECT
PALMETTO BEND DAM

HOLE #01 (I 1) OB. #1 - 13

Location = D/S Crest

Collar Elev. = 25.3

—— = Initial Profile 12/17/79

= Profile 07/03/80 = Profile 09/04/81

= Profile 12/08/83 = Profile 05/23/85

= Profile 03/20/86 = Profile 07/28/86

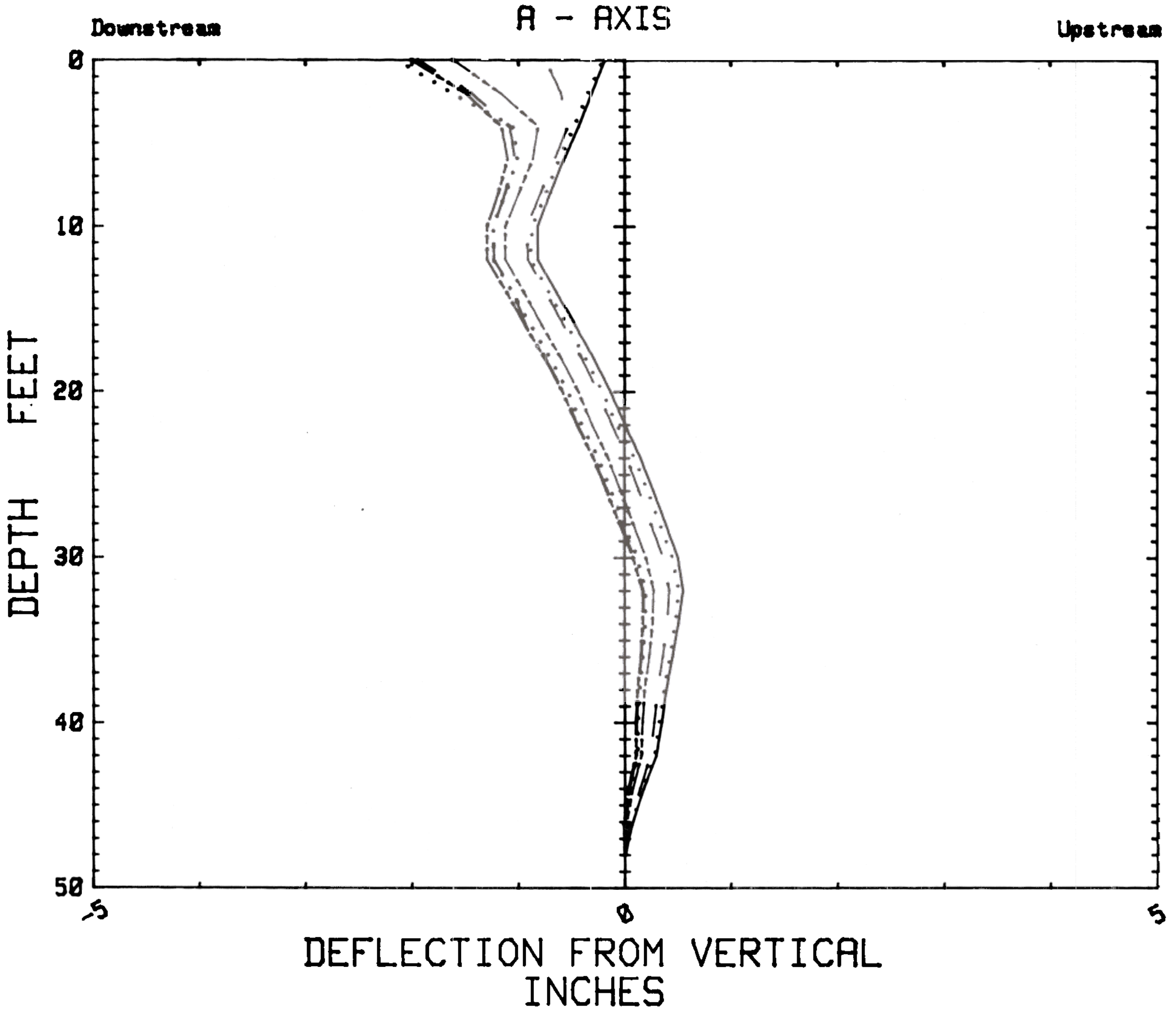
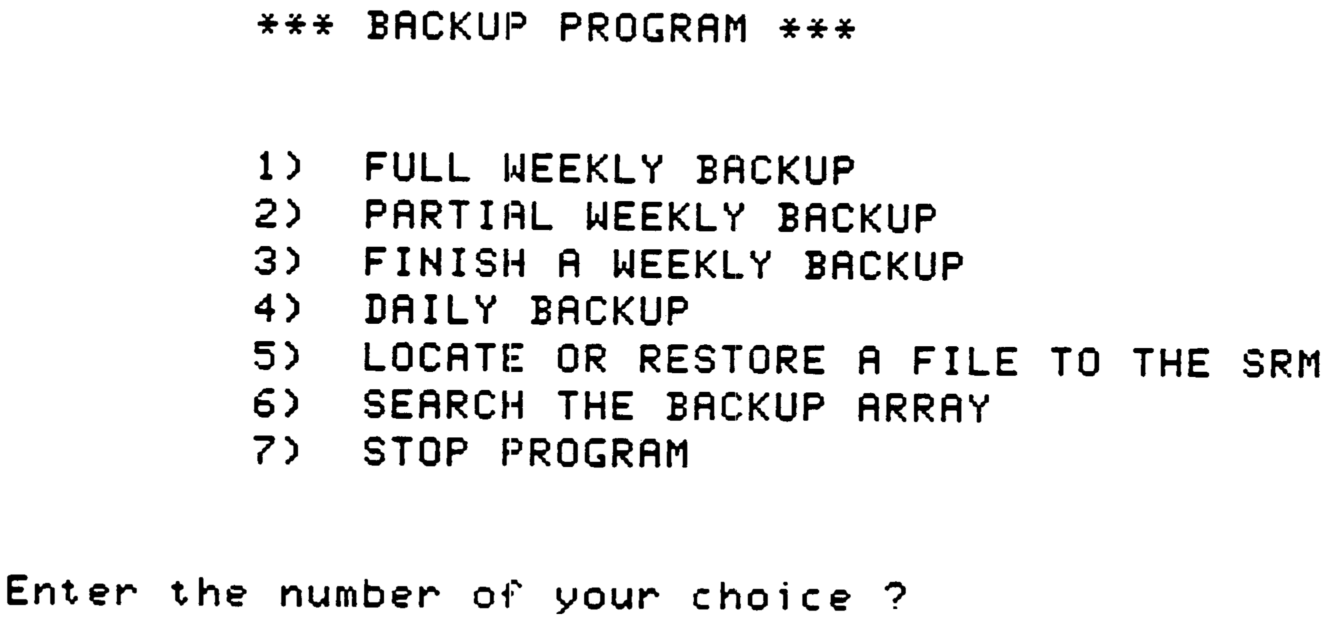


Figure B-17



```
         *** BACKUP PROGRAM ***


         1)   FULL WEEKLY BACKUP
         2)   PARTIAL WEEKLY BACKUP
         3)   FINISH A WEEKLY BACKUP
         4)   DAILY BACKUP
         5)   LOCATE OR RESTORE A FILE TO THE SRM
         6)   SEARCH THE BACKUP ARRAY
         7)   STOP PROGRAM


Enter the number of your choice ?
```

Figure B-18

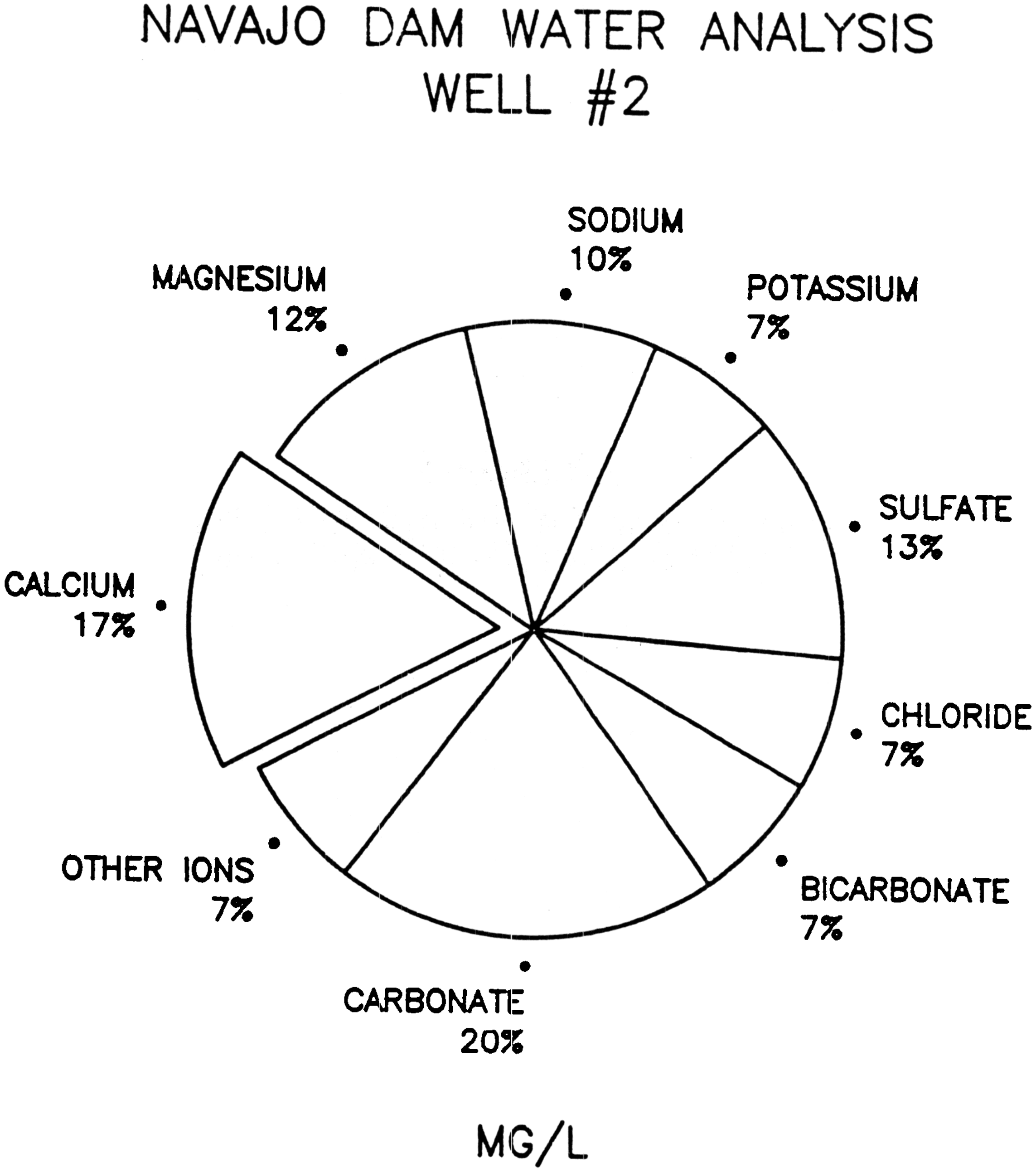

NAVAJO DAM WATER ANALYSIS
WELL #2
SODIUM 10%
POTASSIUM 7%
SULFATE 13%
CHLORIDE 7%
BICARBONATE 7%
CARBONATE 20%
OTHER IONS 7%
CALCIUM 17%
MAGNESIUM 12%
MG/L

Figure B-19

APPENDIX C

AUTOMATION OF THE INSTRUMENTATION AT TWO NEW BUREAU EMBANKMENT DAMS

Appendix C

AUTOMATION OF THE INSTRUMENTATION AT TWO NEW BUREAU EMBANKMENT DAMS

by Bruce C. Murray

Introduction

The Bureau has recently awarded contracts to GEMS (Geotechnical Engineering and Mining Services, Inc.) of Lakewood, Colorado, to automate major portions of the extensive instrumentation facilities at Ridgway Dam in Colorado and Calamus Dam in Nebraska. Ridgway Dam, located approximately 6 miles north of Ridgway, Colorado, is a zoned earthfill embankment having a structural height of 227 feet and a crest length of 2,430 feet whose completion is scheduled for fall 1986. Calamus Dam, located approximately 6 miles northwest of Burwell, Nebraska, is a zoned earthfill embankment having a structural height of 85 feet and a crest length of approximately 7,000 feet that was completed in the fall of 1985.

The extensive instrumentation system designed for Ridgway Dam includes pneumatic, porous-tube and slotted-pipe piezometers, inclinometers, multipoint borehole extensometers, pneumatic and vibrating-wire total pressure cells, foundation baseplates, weirs, embankment and structural measurement points, and strong-motion accelerographs. Much of this instrumentation was specifically designed to monitor the potential instability of the left abutment.

The instrumentation system for Calamus Dam was designed to closely monitor seepage and settlement within the embankment and foundation and to provide the monitoring necessary without being overly committed to one type of instrument whose failure (or partial failure) would severely limit the overall monitoring capability of the system. Of special concern was the monitoring of foundation seepage and the effectiveness of the various design features used to reduce the seepage. The instrumentation system included observation wells, vibrating-wire, pneumatic, and porous-tube piezometers, pneumatic settlement sensors, inclinometers, weirs, foundation baseplates, embankment and structural measurement points, thermistors, and turbidity monitoring devices.

II. Feasibility

The Bureau has long been interested in automating instrumentation and, in fact, has done so with five concrete dams but until now had never automated an embankment dam's instrumentation. The reasons had primarily been the state of the art and economics. The Bureau needed evidence that the necessary equipment and technology had progressed enough to provide accurate, dependable, and affordable automation systems. The systems would also have to pay for themselves in labor savings and other benefits and not just be research projects without cost considerations.

A. **State of the Art.**—Recent developments in mini-pressure transducers, data loggers, microprocessors, and radio and satellite transmittal of data have in a short time taken automation systems equipment from research items to shelf items. It seemed that almost overnight the technology had developed accurate, dependable, and potentially affordable systems. GEMS, one notable company in the field, had developed the necessary computer hardware and software, pressure transducer, and data logger equipment and successfully installed the equipment at remote damsites. At one of the world's largest pumped storage projects in Bathe

County, Virginia, GEMS automated the monitoring of 560 vibrating-wire and pneumatic piezometers. Bureau personnel visited this site in October 1984, and were most impressed by how the automated monitoring of the pneumatic piezometers had effectively eliminated the significant human error involved in monitoring pneumatic instruments with an automatic and even flow of pneumatic pressure.

B. **Economics.**—Affordability of the equipment was one important economic hurdle, but the Bureau also needed to prove that the automation systems were worth the expenditure. Could they pay for themselves in labor savings and other benefits over a reasonable life expectancy of the equipment? To address this issue, the Bureau ran cost/benefit analyses for several dams recently completed or nearing completion because dams of this era would have the most instrumentation and the most labor to be saved by automation.

At present, Calamus and Ridgway Dams were the only two found economically feasible to automate large portions of their instrumentation monitoring systems. In the case of Calamus, a feasibility cost estimate of the automation system was almost totally balanced out by the present worth of labor savings over the first 15 years of use. Other benefits did not need to be considered. Not all cases are so clear cut economically. In Ridgway's case, the cost of the system exceeded the present worth of the first 15 years of labor savings by nearly $87,000.

The following intangible benefits were believed to be worthy justification of the additional cost:

- Significant concerns exist regarding the stability of the left abutment of Ridgway Dam. Extensometers, slotted-pipe piezometers, and vibrating-wire total pressure cells in this area will need to be monitored very closely. Manual readings of these instruments are, of course, possible. However, automating these instruments allows them to be read as frequently as once very 4 hours without additional cost. This capability may be very important should some problems develop at the left abutment during first filling of the reservoir. Such a reading frequency, done manually, would cause significant problems to the field personnel and might lead to other aspects of first filling monitoring being short-changed. While the above statements refer to the left abutment area, the same principle would apply to all automated instrumentation at the dam.

- Since automated readings are performed in a totally consistent manner, automation leads to a significant improvement in instrumentation data quality. Small changes in readings therefore are known to have actually occurred and anomalies and trends can more easily be evaluated. With manual readings, human variations in performing the readings and occasional human errors are present and always introduce uncertainty concerning the validity of the instrumentation data.

- Severe weather conditions, which can be expected to occur at Ridgway Dam, may affect the ability of field personnel to perform manual readings at various times. The automated instrumentation system is designed to perform regardless of the weather.

- The automated instrumentation system will collect and transmit data to the E&R (Engineering and Research) Center faster than could be accomplished manually. This will allow for more timely review of data and earlier recognition of potential problems.

III. Contracting Process

Using the competitive negotiation approach, the contract documents spelled out the technical requirements for the automation system and then the offerors competed on the basis of technical capability and cost for doing the work. With the contractor designing the system to meet Bureau technical requirements, there would be a much better chance of having a well-designed, "state-of-the-art," cost-effective system design. Evaluation of bidders based on cost (35 percent weighting) and technical capability (65 percent weighting) ensured contracting with a technically capable firm, with cost still a significant consideration.

The Bureau's contract entered into through the competitive negotiation process required the contractor to design, supply, and install equipment and materials necessary for automating specific instruments. The instruments to be automated at Calamus Dam included 48 pneumatic piezometers, 28 pneumatic settlement sensors, 16 vibrating-wire piezometers, 70 open-standpipe piezometers, and 1 reservoir level gauge. The instruments to be automated at Ridgway Dam included 73 pneumatic piezometers, 9 pneumatic total pressure cells, 4 vibrating-wire total pressure cells, 19 slotted-pipe piezometers, 8 multipoint extensometers, and 1 reservoir level gauge. The contractor was also required to provide all necessary hardware and software to transmit the readings by satellite to the Bureau's E&R Center in Denver, Colorado, documentation of the software, and servicing of the system for a specified period following acceptance.

IV. Major Design Aspects

A. Equipment

1. Power Requirements.—What is the status of electrical power on site? Is it reliable or susceptible to outages during storms? Data collecting during bad weather or after earthquakes may be a necessity. Would it be less expensive to get power to the data acquisition equipment or to move the data acquisition units to the power? Can all the data automation and acquisition equipment run from batteries, and if so, what additional costs are involved?

Field data acquisition equipment should have on-board, battery-backed memory in case of power loss. The battery-backed feature will allow a system to recover on its own without having to manually reload operating software.

2. Intelligence.—Each site and type of sensor monitored requires varying amounts of intelligence in the system. Should raw data be transmitted from the site or should it be reduced?

A common software function is the "percent-variable" function which compares the past reading to the current reading. If there has been a change of a certain percent, then the reading with time-stamp is stored. This function allows the units to collect the data without filling the memory with unchanged data. Additional intelligence and on-board math capabilities are required for the "percent-variable" software.

Complex communications systems require additional intelligence. Different types of communications, especially automation systems, that use several communications methods, e.g., communications cable, fiber-optics, UHF radio, meteor burst radio, and satellite, require additional intelligence to manage the communications software.

3. Memory Capacity.—Different types of memory, internal and external, are impacted by several factors. The choice of the proper type of memory depends on the size, type, and environmental conditions at the project. For example, external memory devices like magnetic tape or floppy disk have never been suitable for cold, wet, or even humid conditions. The price of internal ROM (read only memory) and RAM (random access memory) has fallen to the range where they are extremely cost efficient. Bubble memory has all the necessary features to be used for geotechnical monitoring, but has never been commercially developed.

The amount of memory necessary for the automation system is governed by the hypothetical situation where satellite data transmission breaks down when instruments are being read as frequently as possible. Since 50 readings can be stored in the automation system, and hourly readings are possible, under the worse possible case, about 2 days worth of data can be stored before manual or telephone retrieval of data needs to be accomplished.

4. Stability.—The accuracy and stability of the automation equipment should always be better than that of the sensors being monitored. Many of the stability problems arise from the fluctuations in voltage or excitation energy supplied to the sensors. Special care should be taken to ensure that stable power is provided.

Some pieces of automation equipment often require pressure sensors of their own. Pneumatic and certain types of reservoir level automation equipment require precise pressure transducers. Special care must be taken in selection of the pneumatic automation transducer, so its sensitivity and accuracy are better than those of the sensor it is automating. If sensors are susceptible to drift, then precautions must be taken to provide internal calibration, software correction, or periodic adjustments.

5. **Reliability.**—Manual reading systems must always be easily accessible in case the automation system fails. Accessibility to manual readings are especially important with instruments such as standpipe piezometers, because with a sensor installed down the standpipe, access for a water level indicator can be cut off. If this is the case, a "bubbler" type line can be included with the electronic sensor. The "bubbler" line will assist not only in manual readings but also in checking the accuracy and drift of the electronic sensor.

6. **Packaging and Serviceability.**—Packaging is approximately 10-15 percent of the overall effort involved in automation equipment. Properly designed, manufactured, and packaged equipment will fit nearly any and all requirements. Integral to packaging is the serviceability.

Instrument automation equipment is often restricted to a certain size. Remote single sensor automation equipment especially for standpipe piezometers requires a compact packaging scheme.

Instrument automation equipment is often packaged in two enclosures, one to hold the electronics and one to provide protection from the weather and vandals. Standpipe piezometers are a good example of this. The outside enclosures may be large steel cases mounted on top of the protective pipe (pedestal) or vaults buried in the ground. The major tradeoffs include accessibility, serviceability, resistance to vandals, and exposure to the elements (potential flooding for underground vaults or exposure to lightning for pedestals).

UHF radio links sometimes present problems because of the antennas. The omni-directional antenna cannot be located inside a metal enclosure due to radio interference. Locating the antenna outside the enclosure involves running an antenna lead and securing the antenna in a vandal resistant location.

B. Communications

1. **Cost Effectiveness.**—Selection of the proper type or mixture of communications methods is one of the most important parts of developing a cost-effective geotechnical automation system. Communications systems are normally broken into two types, local for on-site data transmission and remote for transmission from the site across the state or country to the main office or headquarters.

The major aspect of proper communications design is to strike an appropriate balance between buried communications cable and UHF radio links. The theoretical breakeven point for buried cable versus UHF radio links is between 150 to 300 feet depending on soil type. Installations in rock have a breakeven of 50 to 80 feet depending on the type of rock.

Remote transmission of data generally presents two choices, telephone or GOES satellite. Telephone transmission of data is straightforward and very cost effective. The data are, however, at the mercy of the national telephone system and susceptible to outages during storms or earthquakes. Transmission via the GOES (Geostationary Operating Environmental Satellite) can also be very cost effective and efficient.

2. **Communications Protocol and Data Format.**—Efficiency is a concern not only when selecting and placing communication equipment but also when developing protocol and data format. A well designed integrated system should have consistent and efficient data management that provides output in a readily recognizable form.

3. **Remote Control-Remote Status/Diagnostics.**—Remote control of a system is very important in order to be able to tune the collection of the data to fit the time of year or some event (storm, earthquake, etc.). Anytime there is a two-way link, such as telephone, the remote control function is available. It is even a good reason to have telephone as a backup communication method when satellite communication is the primary method. A key sign of well designed geotechnical electronics is the ability of the hardware to send status information such as battery voltages, sensor status, piezometer line status (okay, clogged, or open), site temperatures, humidity within enclosures, etc.

C. Data Base Hardware and Software

The geotechnical data base is the final link in the integrated system approach to geotechnical monitoring. The rapid and frequent collection of data could inundate a manual data reduction system. Therefore, a complete data management system that interfaces with the data collection hardware and provides data verification, reduction, storage, printing, and plotting is best.

The emergence of the low-cost PC (personal computer) market has provided an excellent unit for geotechnical data base software. The equipment is inexpensive, in common use, easy to use, supported by many companies, capable of handling the data for every size and type of project. When compared to a main frame system that is commonly under the control of departments other than engineering, the PC is an obvious choice. Properly configured with sufficient memory and proper type of memory media, the geotechnical data base resident on a PC can handle any type or number of projects.

The major features of a professional geotechnical data base management system are:

- Modular design so that the system can grow and new instruments and types of data can be added.
- Menu-driven so that nontechnical personnel can operate it.
- Data verification so that bad, out-of-range, and duplicate data are identified immediately upon entry into the system.
- Data reduction for all types of instruments should be included to provide proper and complete data reduction.
- Direct and automatic data entry from data acquisition hardware. The software should have the ability to interface with all types of data collection and communications systems.
- The system should be able to be accessed from the outside via telephone line and data reviewed and additional data input.
- Data integrity and system security features. Access to the system should be limited by passwords.
- Dot matrix and X-Y plotter graphics. The system should support a wide range of printers and plotters.

At Ridgway Dam, the 113 instruments automated are spread over a 3-square mile area and most of the automation and data acquisition units will be exposed to −40 °C (−40 °F) temperature and must operate continuously on battery power for periods as long as 6 months. As part of the system, there will be 19 radio equipped TERRAPOINT units and 9 TERRATRAC data acquisition and communication systems. All the TERRAPOINT remote units will be under the control of two TERRATRAC units, and the data from those units will be gathered in one TERRATRAC for transmission by a Data Collection Platform to the GOES West satellite.

V. Conclusions

A. In some instances, with normal monitoring requirements, the Bureau has found that even the cost of new affordable automation equipment exceeds the reasonable expected cost of labor required to take the readings and is therefore unwarranted. Timing of the automation can be critical because if first filling has already been completed, then the opportunity for the greatest labor savings may have been lost.

B. The Bureau speculates that intangible factors such as lack of available or skilled manpower, unusual reading frequency requirements, the need for some kind of warning system related to specific variables, remote locations, etc., may be in future instances deciding if not overriding decision factors in automating instrumentation.

C. The Bureau is excited and optimistic about our contracts to automate major portions of the extensive instrumentation at Ridgway and Calamus Dams but we are not naive. Even though the Bureau made sure that similar situations had been successful elsewhere, it was emphasized in the specifications that the automation system would not be allowed to impact the taking of manual readings. Future Bureau plans for automating embankment dams will to a great degree depend on the success with Calamus and Ridgway Dams.

D. Until such time as the Bureau can evaluate these initial efforts, it will proceed cautiously and explore the feasibility of instrumentation automation on a case-by-case basis. The most ideal time to determine the feasibility of automation is during design because many design decisions can help cut the cost of later automation.

E. It is often hard to justify automating large portions of the instrumentation, but because of reading schedules, specific concerns, weather, or whatever it may be quite justified in automating one type of instrument or the instruments in one specific problem area of the dam.

F. Automating instrumentation may lead to elimination or neglect of human judgment and field observation and a false sense of security. These possible problems need to be recognized and avoided.

G. The Bureau is anxious to hear of other automation experiences.

APPENDIX D
SUMMARY OF INSTRUMENTATION IN USBR EMBANKMENT DAMS

Appendix D

SUMMARY OF INSTRUMENTATION IN USBR EMBANKMENT DAMS

GLOSSARY OF INSTRUMENTS

VMD — Vibration measuring device
BP — Base plate
CM — Carlson meters
CMD — Crack measurement devices
EP — Electrical self-potential monitoring
MPX — Multi-point extensometers
GP — Pneumatic piezometer
DM — Drain monitoring
HPI — Hydrostatic pressure indicator
TTP — Hydraulic piezometers
IVM — Internal vertical movement
IN — Inclinometer
INN — Inclinometer (normal)
INF — Inclinometer (fixed)
IS — Inclinometer settlement
MP — Embankment measurement points and/or structural measurement points
OW — Observation wells
PSS — Pneumatic settlement sensors
PTP — Porous-tube piezometer
RA — Radiosonde
SM — Seepage measurement
SPP — Slotted-pipe piezometers
SS — Shear strips
EXO — Extensometer (other)
TPC — Total pressure cells
TL — Tiltmeter
TM — Thermotic monitoring
VWP — Vibrating-wire piezometer
VWS — Vibrating-wire settlement sensors
WQ — Water quality
WS — Watersonde
UP — Uplift pressure

GLOSSARY OF TYPES OF DAMS

A = zoned earthfill
B = modified homogeneous earthfill

C = concrete gate structure, embankment wings
D = homogeneous earthfill, concrete slabs on upstream face
E = earthfill, puddled core diaphragm
F = earthfill, concrete-lined
G = rolled earthfill
H = concrete thin arch
I = Semihydraulic earthfill
J = hydraulic earthfill
K = zoned earthfill embankment
L = zoned earthfill and concrete spillway
M = homogeneous earthfill
N = earthfill
O = random fill earth, steel faced
P = earth and rock fill
Q = zoned earthfill, asphaltic concrete on upstream slopes
R = diaphragm-type earthfill
S = concrete gravity, embankment wings
T = zoned earthfill, concrete faced
U = homogenous earthfill, concrete faced
V = zoned earthfill, concrete gravity spillway and gate sections
W = concrete agee-gated weir, embankment wings
X = zoned earthfill and sandstone fragment fill
Y = concrete gate structure
Z = compacted earthfill
AA = earth, concrete core wall diaphragm
BB = zoned, rolled earth and rockfill
CC = concrete, slab-and-buttress weir, embankment wing
DD = rockfill
EE = rolled earth, sand, gravel, and rockfill
FF = zoned earth and rockfill
GG = thin core rockfill

SUMMARY OF INSTRUMENTATION IN USBR EMBANKMENT DAMS

Name of Dam	Type	Year Completed	Height in meters	Length in meters	Type of instrument
Agate	A	1966	26	1,158	16 MP, 2 SM
Agency Valley	A	1935	34	564	111 MP
Alcova	A	1938	81	233	41 MP, 2 SM
Anderson Ranch	A	1950	139	411	23 TTP, 2 IVM, 22 MP
Anita	B	1937	13	320	None
Arbuckle	A	1966	46	572	27 MP, 1 SM
Arcadia Diversion	C	1962	2	2,426	23 PTP
Arthur R. Bowman	A	1961	73	241	22 MP, 1 SM 9 WQ
Arthur V. Watkins	A	1964	11	23,367	94 BP, 63 TTP, 18 IVM, 149 MP
Avalon	A	1907	18	312	1 SM
Batu	A	*	45.7	610	2 INN, 21 VWP, 3 OW, 14 PTP, 4 SM, 36 MP

SUMMARY OF INSTRUMENTATION IN USBR EMBANKMENT DAMS—continued

Name of Dam	Type	Year Completed	Height in meters	Length in meters	Type of instrument
Belle Fourche	D	1911	37	,909	6 OW, 1 PTP, 1 SM
Big Sandy	A	1952	26	716	10 MP, 12 OW
Blue Mesa	A	1966	119	239	28 MP, 1 SM
Boca	A	1939	35	497	80 MP, 1 SM
Bonny	B	1951	48	2,804	7 BP, 50 TTP, 6 IVM, 90 MP, 6 OW, 4 SM
Bottle Hollow	A	1970	23	152	18 MP, 6 SM
Box Butte	A	1946	27	,679	None
Boyson	A	1952	67	348	32 TTP, 2 IVM, 26 MP
Bradbury	A	1953	85	1,021	5 BP, 50 TTP, 2 IVM, 61 MP, 3 SM
Brantley	Y	*	36.5	6,400	2 GP, 155 OW, 41 SPP
Bull Lake	B	1938	25	1,053	42 HPI, 140 MP, 1 SM,
Bully Creek	A	1963	37	936	28 MP
Bumping Lake	E	1910	19	892	19 MP, 5 SM, 5 PTP
Caballo	A	1938	29	,389	4 BP, 44 HPI, 176 MP, 4 SM, 4 SPP, 91 WQ
Calamus	G	1985	29.3	2,195.	12 BP, 48 GP, 9 IS, 28 PSS 100 PTP, 3 INN
Carl T. Curtis	A	1977	85.4	,288.1	3 BP, 5 GP, 30 MP, 17 OW, 1 SM
Carpenteria	F	1954	9	411	3 SM
Carter Lake	A	1952	23	351	40 TTP, 4 IVM, 71 MP, 3 SM
Cascade	A	1948	33	239	7 SM
Casitas	A	1959	102	610	4 IVM, 89 MP, 2 OW, 14 PTP
Causey	A	1966	66	258	17 MP, 1 SM
Cedar Bluff	A	1951	62	3,828	15 BP, 14 TTP, 16 IVM, 73 MP, 13 OW
Cheney	G	1965	38	7,455	71 MP
Choke Canyon	A	1982	43.	5,631.4	7 BP, 79 MP, 28 PTP, 25 SPP
Clark Canyon	A	1964	45	884	21 MP, 33 OW, 3 SM
Clear Lake	H	1964	25	123	None
Cle Elum	A	1933	50	549	6 MP, 2 SPP
Cold Springs	A	1908	31	1,052	31 PTP, 2 SM

SUMMARY OF INSTRUMENTATION IN USBR EMBANKMENT DAMS—continued

Name of Dam	Type	Year Completed	Height in meters	Length in meters	Type of instrument
Como	I	1954	21	777	7 SM
Conconully	J	1968	22	328	1 SM
Contra Loma	A	1967	33	320	13 MP, 30 OW, 3 SM
Crane Prairie	A	1940	11	87	None
Crawford	A	1962	49	177	35 TTP, 2 IVM, 27 MP, 4 SM
Crescent Lake	A	1956	12	137	None
Currant Creek	K	1977	40	488	21 MP, 20 OW, 20 SM, 67 SPP
Cutter	A	1972	44	291	16 MP, 2 INN
Davis	L	1950	61	488	7 PTP, 8 SM, 27 UP, 52 TTP, 9 IVM, 45 MP
Davis Creek	G	**	46.6	883.9	None
Deaver	M	1918	4	396	None
Deer Creek	A	1941	72	397	5 IVM, 114 MP
Deer Flat	A	1911	5	290	32 PTP, 8 SM
Deerfield	A	1946	41	251	34 MP, 13 OW, 1 SM
Dickinson	M	1950	19	693	3 OW, 10 PTP, 1 SM
Dixon Canyon	A	1949	73	386	19 TTP, 44 MP, 1 SM
Dry Falls	A	1949	37	2,987	98 MP
Echo	A	1931	48	575	115 MP
Eden	N	1910	8	1,067	None
Eklutna	P	1965	17.1	248.4	None
El Vado	O	1955	53	404	41 MP, 1 SM
Emigrant	A	1960	62	229	19 TTP, 5 IVM, 26 MP
Enders	M	1951	41	793	8 BP, 23 TTP, 4 IVM, 66 MP, 42 OW, 12 SM
Fish Lake	P	1956	15	293	1 SM
Flatiron	A	1953	26	526	None
Fontenelle	A	1964	42	,652	322 EXO, 222 MP, 34 OW, 19 PTP, 13 SM, 10 SPP
Fort Cobb	M	1959	37	3,018	28 TTP, 17 IVM, 51 MP, 1 SM
Foss	A	1961	43	5,526	53 TTP, 6 IVM, 56 MP, 41 OW, 17 PTP, 3 SM, 15 SPP
Fresno	M	1939	34	631	8 BP, 24 TTP, 2 IVM, 131 MP
Fruitgrowers	M	1938	7	463	43 MP, 21 PTP, 7 INN, 3 SM, 36 SPP

SUMMARY OF INSTRUMENTATION IN USBR EMBANKMENT DAMS—continued

Name of Dam	Type	Year Completed	Height in meters	Length in meters	Type of instrument
Funks	A	1977		445.1	22 MP, 2 OW, 1 SM
Glen Anne	Q	1953	41	73	11 MP, 10 SM
Glen Elder	A	1969	15	4,560	36 MP, 25 OW
Cawker City Dike	A	1969	15	4,560	9 OW
Downs Protective Dike	A	1968	27	6,035	9 OW, 6 SM
Glendo	A	1958	58	639	32 MP, 18 PTP, 10 SM
Granby	A	1950	91	262	18 TTP, 2 IVM, 82 MP, 6 SM
Grand Mesa Dams —					
Atkinson	N	1965	11	229	3 SM
Big Creek	N	1893	7	157	2 SM
Big Meadows	N	1899	6	136	4 SM
Bonham	N	1962	12	457	2 SM
Cottonwood (#1)	N	1962	6	125	1 SM
Cottonwood (#2)	N	1966	6	41	1 SM
Cottonwood (#4)	N	1974	4	73	1 SM
Decamp	N	1962	5	244	1 SM
Forty Acres	N	1970	4	61	3 SM
Kitson	N	1974	5	155	2 SM
Lambert	N	1965	5	366	1 SM
Little Meadow	N	1968	4	44	1 SM
Neversweat	N	1969	5	49	1 SM
Silver Lake	N	1966	6	70	2 SM
Grassy Lake	A	1939	36	357	66 MP, 4 SM
Gray Reef	A	1961	11	198	1 SM
Green Mountain	A	1943	94	351	28 TTP, 5 IVM, 37 MP, 3 OW
Guajataca	I	1927	37	316	9 INN, 38 MP, 3 OW, 12 PTP, 5 SM, 26 SPP
Guernsey	R	1927	41	171	3 SM
Haystack	A	1957	32	366	34 MP
Heart Butte	M	1949	43	564	22 TTP, 3 IVM, 24 MP, 10 OW, 2 SM
Helena Valley	A	1958	28	808	60 OW, 5 SM
Heron	P	1971	84	372	24 TTP, 1 IVM, 29 MP, 5 SM
Horseshoe	N	1946	59	347	17 MP, 5 SM
Horsetooth	A	1949	47	561	16 TTP, 2 IVM, 53 MP, 5 SM
Santana Dike	A	1949	9	106	5 OW, 1 SM
Howard Prairie	A	1958	30	317	16 MP
Hubbard	N	1902	9	2,438	None
Huntington North	A	1966	23	883	40 MP, 27 OW
Hyatt Prairie	P	1961	16	236	1 SM
Hyrum	M	1935	35	165	72 MP
Island Park	A	1938	28	2,880	45 MP, 2 OW,

SUMMARY OF INSTRUMENTATION IN USBR EMBANKMENT DAMS—continued

Name of Dam	Type	Year Completed	Height in meters	Length in meters	Type of instrument
					6 PTP, 6 SM
Jackson Creek	A	1965	58	305	None
Jackson Gulch	A	1949	55	579	7 TTP, 8 IVM, 27 MP, 3 SM
Jackson Lake	S	1911	20	,500	64 GP, 22 OW, 9 SM
Jacobsen	M	1973	21	1,257	58 MP, 24 OW, 37 SPP
Jamestown	A	1953	34	432	31 MP, 6 OW
Joe Wright	N	1980	45.	651.2	6 PTP, 5 SM, 10 SPP
Joe's Valley	A	1966	59	229	11 MP, 25 PTP, 10 SM
Jordanelle	G	*	90.2	853.4	10 INN
Kachess	A	1936	35	427	6 MP, 2 SM
Keechelus	A	1917	39	1,996	3 SM
Keene Creek	A	1959	24	170	22 MP
Keyhole	A	1952	51	1,042	33 TTP, 26 IVM, 57 MP, 2 SM
Kirwin	A	1955	52	3,855	8 TTP, 95 MP, 9 OW
Lahontan	A	1915	49	1,646	None
Lake Alice	M	1913	11	945	10 OW, 1 SM 12 SPP
Lake Minatare	T	1915	35	1,146	1 SM
Lake Sherburne	M	1921	29	331	2 INN, 21 MP, 17 OW, 7 PTP
Lauro	A	1952	42	165	5 MP, 9 PTP, 3 SM
Lemon	A	1963	87	415	32 MP
Lewiston Diversion	A	1963	28	227	7 MP
Little Panoche	A	1966	146	439	119 MP
Little Wood River	A	1960	39	945	10 MP, 2 SM
Lonetree	N	1976	12	1,579	92 OW, 1 INN
Lovewell	A	1957	28	2,591	57 TTP, 11 IVM, 85 MP, 18 OW, 12 PTP
Mann Creek	N	1967	45	358	20 MP, 4 SM
Marble Bluff	A	1975	7	494	5 OW, 2 SM, 6 SPP
Mark Edson	A	1962	50	411	None
Martinez	B	1947	19	366	1 SM
Mary's Lake Dikes	M				
No. 1		1949	9	250	SM
No. 2		1949	11	290	
Mason	P	1968	53	273	14 MP, 3 OW
McGee Creek	A	*	50.0	600.2	56 GP, 26 MP, 1 PTP, 24 TPC, 1 INN
McKay	U	1927	50	823	22 MP, 14 SM, 30 SPP, 48 WQ

SUMMARY OF INSTRUMENTATION IN USBR EMBANKMENT DAMS—continued

Name of Dam	Type	Year Completed	Height in meters	Length in meters	Type of instrument
McMillan	A	1908			1 SM
McPhee	EE	1984			10 MPX, 96 GP, 98 IS, 188 MP, 64 PSS, 8 PTP, 14 SPP, 5 INN
Great Cut Dike	EE	1984	19.5	579.3	2 INN
Medicine Creek	A	1949	50	,727	4 BP, 24 TTP, 10 IVM, 73 MP, 23 OW, 6 SM
Meeks Cabin	P	1971	55	953	30 MP, 5 PTP 9 SM, 1 INN
Merritt	A	1964	38	982	29 TTP, 3 IVM, 22 MP, 26 OW, 13 PTP, 42 SM, 4 SPP, 408 WQ
Midview	A	1937	16	202	73 MP
Minidoka	V	1909	26	,364	5 SM, 17 SPP
Moon Lake	A	1938	31	338	78 MP
Mountain Park	H	1975	32	151	26 MP
Mt. Elbert	A	1981	28.0	792.7	6 INN, 26 MP, 85 OW, 46 PTP, 10 VWP
Navajo	A	1963	123	1,112	3 DM, 79 MP, 40 TTP, 81 IVM, 9 OW, 20 PTP, 10 SM, 26 SPP, 258 WQ
New Melones	DD	1979	190.5	503.0	37 GP, 41 IS, 120 MP, 14 OW, 2 SM, 6 INN
New Waddell	GG	**	90	2,440	None
Newton	A	1946	31	1,018	8 MP, 3 PTP, 4 SM
Norman	A	1965	44	2,214	52 MP
North	A	1951	44	442	4 BP, 21 TTP, 2 IVM, 17 MP, 2 SM
Norton	A	1964	40	1,966	46 MP, 20 OW
Oat	N	†	Low	Unknown	None
Ochoco	A	1950	38	411	None
O'Neill	A	1967	27	4,359	27 OW, 25 WQ 6 INN
O'Sullivan	A	1949	61	5,791	36 TTP, 2 IVM, 66 MP, 5 SM
Ortega	F	1954	40	132	1 SM
Pactola	A	1956	70	383	63 MP, 3 PTP, 1 SM
Palisades	A	1957	82	640	39 TTP, 4 IVM, 30 MP, 2 OW, 4 SM
Palmetto Bend	N	1978	21	13,904	87 MP, 58 OW,

SUMMARY OF INSTRUMENTATION IN USBR EMBANKMENT DAMS—continued

Name of Dam	Type	Year Completed	Height in meters	Length in meters	Type of instrument
					3 SPP, 4 INN, 32 PTP, 3 SM
Palo Verde	W	1957	14	396	13 MP
Paonia	A	1962	61	235	8 MP, 2 SM
Picacho (North)	N	1954	13	490	None
(South)	N	1954	9	490	
Pilot Butte #1	A	1926	16	396	7 PTP, 3 SM
#2	A	1926	8	366	
#3	A	1926	4	,036	
Pineview	A	1937	40	183	7 MP
Pinto	A	1948	40	579	49 TTP, 4 IVM 57 MP, 2 SM
Platoro	A	1951	50	450	6 MP, 1 SM
Prosser Creek	A	1973	50	588	15 MP, 3 SM
Putah Diversion	W	1957	3	277	22 PTP
Rattlesnake	A	1952	40	335	None
Red Fleet	A	1980	44	518	27 GP, 29 DM, 34 MP, 26 OW, 6 SM, 24 SPP, 10 INN
Red Willow	A	1962	38	963	28 TTP, 3 IVM, 31 MP, 21 OW, 13 SM
Reservoir A	N	1922	18	671	1 SM
Ridgway	G	*	69.2	740.9	3 BP, 12 MPX, 47 GP, 9 INN, 11 PTP, 23 SPP, 13 TPC, 12 VWP
Rifle Gap	A	1967	48	442	30 MP, 10 OW, 2 SM
Ririe	N	1977	77	326	31 CM, 9 MP, 8 OW, 8 INN, 25 SM, 42 SPP, 2 TL
Ruedi	N	1968	98	318	16 MP, 6 OW, 4 SM
Rye Patch	M	1976	24	327	54 MP, 5 SM
Salmon Lake	A	1921	16	381	None
San Justo	N	*	43	220.1	9 OW, 16 PTP
San Luis	A	1967	116	5,669	6 BP, 81 TTP, 7 IVM, 5 INF, 62 MP, 15 OW, 45 PTP, 17 INN, 13 SM, 71 VWP
Sanford	A	1965	69	1,945	5 BP, 115 TTP, 2 IVM, 50 MP, 17 OW, 32 PTP, 4 SM, 25 WQ
Scofield	A	1946	38	175	6 MP, 8 SM

SUMMARY OF INSTRUMENTATION IN USBR EMBANKMENT DAMS—continued

Name of Dam	Type	Year Completed	Height in meters	Length in meters	Type of instrument
Scoggins	X	1975	46	841	3 BP, 36 TTP, 6 IVM, 66 MP, 18 OW, 7 SM, 4 INN
Senator Wash	A	1966	29	714	13 TTP, 14 MP, 28 OW, 1 SM, 14 SPP
Shadehill	B	1951	44	3,915	13 BP, 23 TTP, 2 IVM, 40 MP
Shadow Mt.	A	1946	19	938	None
Sherman	M	1962	41	1,356	4 BP, 26 TTP, 1 IVM, 35 MP, 33 OW, 5 PTP, 3 SM
Silver Jack	A	1971	53	320	25 MP, 9 OW, 5 SM
Slaterville Diversion	C	1957	2	49	6 PTP
Sly Park	A	1955	58	232	13 TTP, 6 IVM, 47 MP, 3 SM
Soldier Canyon	A	1949	69	438	17 TTP, 49 MP, 3 SM
Soldier Creek	A	1974	76	393	76 EXO, 33 MP 14 OW, 38 PTP, 10 SM, 8 WQ
Soldiers Meadow	N	1923	17	163	12 PTP, 2 SM
Spring Canyon	A	1949	67	341	19 TTP, 39 MP, 2 OW
Spring Creek Debris	N	1963	60	338	17 MP, 5 SM
Stampede	A	1970	73	461	32 MP, 16 PTP, 2 SM
Starvation	A	1970	61	936	44 MP, 33 PTP, 14 SM, 56 WQ
Stateline	N	1978	39	884	10 GP, 40 MP, 4 OW
Steinaker	A	1961	49	609	41 TTP, 1 IVM, 23 MP, 1 SM
Stoddard Diversion	Y	1956	2	34	6 PTP
Stubblefield	B	1954	14	7,745	None
Sugar Loaf	N	1968	50	616	15 MP, 19 OW, 2 SM
Sugar Pine	P	1980	58	183	11 MPX, 21 GP, 30 TTP, 20 IVM, 20 MP, 4 PTP, 1 SM, 29 TPC, 8 WS, 6 INN
Sumner	A	1937	50	940	5 SM
Taylor Park	A	1937	63	206	53 MP
Terminal	Z	1959	7	265	None
Tiber	A	1956	62	1,311	19 TTP, 2 IVM,

SUMMARY OF INSTRUMENTATION IN USBR EMBANKMENT DAMS—continued

Name of Dam	Type	Year Completed	Height in meters	Length in meters	Type of instrument
					80 MP, 2 SM
Tieton	AA	1925	97	280	63 MP, 3 SM, 6 SPP
Toa Vaca	FF	1972	65.5	530.3	4 IVM, 40 MP, 12 OW, 8 SM
Trenton	A	1953	44	2,621	8 BP, 19 TTP, 187 MP, 20 OW, 9 SM
Trinity	A	1962	164	747	54 TTP, 5 IVM, 54 MP, 16 PTP, 186 SM
Twin Buttes	A	1963	41	12,942	64 MP, 83 OW, 11 SM, 156 WQ
Twin Lakes	N	1978	30.5	960.4	33 MP, 5 OW, 73 PTP, 7 SM, 17 SPP, 8 VWP
Twitchell	A	1958	73	550	23 TTP, 13 IVM, 33 MP, 1 SM
Unity	A	1938	25	212	49 MP
Ute	A	1962	40.2	652.3	None
Vallecito	A	1941	49	,222	22 TTP, 4 IVM, 30 MP, 1 SM
Vega	BB	1959	49	640	32 MP, 6 SM
Ver Mejo	CC	1955	2	311	None
Wanship	A	1957	53.3	612.6	44 MP
Wasco	A	1959	18	126	13 MP
Webster	A	1956	47	3,267	91 MP, 16 0W, 2 SM
Whiskeytown	A	1963	86	1,219	25 MP, 12 SM
Wickiup	A	1940	30	4,225	8 MP, 23 PTP, 5 SM, 3 SPP
Willow Creek	B	1911	28	198	14 MP, 2 SM
Willow Creek	A	1953	39	335	None
Wintering	N	1976	12	,579	25 MP, 15 OW

Under construction.
In design.
† In planning stage.

*U.S. GOVERNMENT PRINTING OFFICE:1997-573-998/65010

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.