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CONSTRUCTION MONITORING OF SOFT GROUND RAPID TRANSIT TUNNELS

VOLUME II: APPENDIXES

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FINAL REPORT

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16. Abstract The Urban Mass Transportation Administration (UMTA) Tunneling Program Concentrates its efforts on reducing tunneling costs, minimzing environmental impact and enhancing safety as it applies to the planning, organization, design, construction and maintenance cycles of rapid transit tunnels in the urban environment. This study investigates the area of construction monitoring of rapid transit tunnels in soft ground.

Soft ground tunnel construction monitoring has the potential to reduce construction costs, safety hazards and environmental impacts. Monitoring can diagnose face stability and ground movement problems, and allow appropriate preventive or remedial action. Monitoring provides data for prediction of ground movements and allows the compilation of useful legal documentation. Such data are also required for improving design and prediction methods.

Monitoring practices now in use do not usually allow full utilization of the data for the project from which they were gathered. Deficiencies in present practices are pointed out, and a systematic approach to monitoring is presented. Information presented will aid owners, designers, specification weiters and instrumentation engineers. A computer program for data storage, interpretation and retrieval is proposed. An interim quality control specification for instrumentation procurement is presented, and instrumentation hardware improvements are suggested.

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APPENDIX A

INTERIM

QUALITY CONTROL SPECIFICATION

FOR

PROCUREMENT OF GEOTECHNICAL

INSTRUMENTATION FOR USE DURING

CONSTRUCTION MONITORING OF SOFT

GROUND RAPID TRANSIT TUNNELS

CONTENTS

1. INTRODUCTION

The following Quality Control Specifications utilized MIL. SPECS. and Federal Standards as guidelines. Copies of MIL. SPECS. can be obtained by telephoning the Naval Publications and Forms Center at (215) 697-3321.

2. SCOPE

The purpose of this Quality Control Specification is to define and standardize the requirements for geotechnical field instrumentation. The provisions of this specification are not intended to limit or inhibit advancement in the art of electrical or mechanical engineering but rather to ensure uniformity, long life of equipment, ease and low cost of maintenance, and safety. This specification is an interim measure, for use pending preparation and publication of a complete self-contained Quality Control Specification for Instrument Procurement. This interim specification is intended for use as a guide to direct the attention of manufacturers and users towards those factors which are critical in manufacturing geotechnical instruments for use during construction monitoring of soft ground rapid transit tunnels.

It is recognized that not all parts of this specification are applicable to all geotechnical instruments. However, geotechnical instruments must conform with all applicable parts of this specification.

The specification covers the mechanical, electrical, calibration, quality assurance and documentation requirements of all geotechnical field instrumentation.

3. MECHANICAL REQUIREMENTS

3.1 Packaging

(a) Packaging of the electronic assemblies must ensure that the unit will operate in an outdoor environment of dust, rain and snow without additional covering protection. The housing itself must meet the watertightness requirements of MIL-STD-108E and construction requirements of MIL-T-21200 with the exception of the provisions for reinforced corners, mounting feet and stacking. All control shafts and penetrations of housing and panels must be sealed to meet MIL-B-5423.

(b) The housing and control panel must be free of sharp edges and burrs that would lead to personal injury.

(c) The housing and control panel must be resistant to dents, scratches, rust, chemicals and petroleum products.

(d) The housing must be provided with a manually operated relief valve to protect against condensation during altitude and temperature changes.

(e) Convenient carrying handles must be provided on each housing or container.

(f) All chassis assemblies must utilize industrial standards for locking devices on assemblies that can be disassembled.

(g) The unit must be packaged to withstand both air and ground transport without additional packaging.

(h) Materials must be selected to minimize the effects of galvanic corrosion between dissimilar metals. If contacting metals are not adjacent in the galvanic corrosion series, they must be separated by use of an inert intermediate material or by passivation methods.

3.2 <u>Connectors, Panel Controls and Hardware</u>

(a) Control knobs must meet the requirements of MIL-K-3926A and/or MS91528C.

(b) Control knobs must be resistant to rust, chemicals and petroleum products.

(c) Control knobs must have a positive lock feature that ensures they cannot be pulled from or rotated on their mounting shafts. This locking feature must be equivalent to specifications FS-103 and MS91528.

(d) All controls and connectors must be permanently labelled and identified.

(e) All hardware must be corrosion resistant and should meet MIL-STD-202 or equivalent commercial standards.

(f) All housing and panel connectors must be an environmental outdoor type and meet the requirements of MIL-C-26482.

(g) Connectors that are protected by the housing cover when the unit is closed must be provided with a dust cover.

(h). Connectors that penetrate the housing must be provided with a dust cover that is permanently attached to the housing or connector.

3.3 Accessories

Accessories are defined as the interconnect equipment required to operate the field equipment as a system.

(a) Cabling must be of the outdoor variety and be resistant to cold flow, abrasion, chemicals, and petroleum products.

(b) Cabling must be flexible and withstand weathering through a temperature range of -20° to $+80^{\circ}C$.

(c) Cabling breakdown voltage must be rated for or exceed the expected voltage in system use.

(d) If cable splicing is required, a linesman splice must be used. Individual conductors must be insulated with sleeving or shrink tubing of the irradiated polyolefin type. The entire splice must be further protected with an overall outer jacket. If the cable is to be submerged in water or embedded below the ground surface the overall outer jacket must be prepared using a commercial electrical waterproofing kit of the Dow Corning, G.E. or AMP type or similar. If a commercial kit is used, certified test data must be submitted to the user detailing procedures and results of appropriate performance tests. If the cable is neither to be submerged in water nor embedded below the ground surface, an overall outer jacket of shrink irradiated polyolefin tubing may be substituted for the commercial electrical waterproofing kit.

(e) Cable connectors must meet requirements of MIL-C-26482.

(f) All cable connectors must be provided with a dust cover permanently attached to the connector or cable.

(g) All accessories must be packaged in a container for easy control and transport.

(h) All electronic accessories must meet the electrical and mechanical requirements covered in Sections 3.1 and 3.2 above.

(i) Mechanical accessories, e.g. cable reels, support stands, etc. must conform to the requirements of Sections

3.1(b), 3.1(c) and 3.1(e) above.

4. ELECTRICAL REQUIREMENTS

4.1 Power

(a) All units must be capable of operating from an internal rechargeable battery.

(b) The internal battery must be capable of being recharged overnight without removal from the unit.

(c) The battery pack must be replaceable in the field without the need to solder.

(d) The unit must be capable of operating from an auxiliary D.C. source.

(e) If the unit is capable of being operated from a 115V-230V AC source, it must meet the U.L. Requirements for Outdoor Electrical Equipment.

(f) If the unit is fused for external protection, the fuses must be replaceable without disassembly of the unit.

(g) Low voltage cutoff should be provided to extend battery life.

4.2 Printed Circuit Boards (P.C. Boards)

(a) Boards must be of the glass epoxy type.

(b) All P.C. boards must be interchangeable from one unit to another to facilitate field maintenance.

(c) All contacts must be gold-plated to provide maximum resistance to oxidation and intermittent operation.

(d) P.C. edge card connectors must be of the self-wiping bifurcated contact type.

(e) P.C. boards must have a mechanical lock and guide mechanism to ensure proper retention and alignment during transporation and use.

(f) If the equipment is intended for use in a tropical climate, P.C. boards must be coated with a fungicide or conformal coating.

4.3 Wiring and Cabling

(a) All wiring must be resistant to cold flow, abrasion, chemicals and petroleum products.

(b) Insulation resistance and voltage breakdown must be compatible with system requirements.

(c) Where wires and cables pass over or through metal or sharp edges, the wire or cable must be protected.

(d) All wiring and cabling must be laced or positively positioned by clamps and ties in accordance with good manufacturing practices.

(e) Wiring and cabling must facilitate easy field maintenance, assembly and disassembly of the unit.

(f) Interconnecting cable between sensor and readout unit must have an operating temperature range from -20° to $+80^{\circ}C$, and have good resistance to solvents and hydrocarbons. The outer jacket must be flexible, weather resistant, flame retardant and must resist abrasion and cold flow.

5. FACTORY CALIBRATION AND QUALITY ASSURANCE REQUIREMENTS

5.1 Each manufacturer must provide a Master Calibration (Tests Required) sheet with each instrument. The calibration frequency must be clearly specified by a calibration sticker placed on the unit.

5.2 Certification must be provided by the manufacturer with each unit that his test equipment is calibrated and maintained per the test equipment manufacturer's calibration requirements.

5.3 Completed copy of Quality Assurance final inspection report must be provided with each instrument. The report must be in the form of a check list such that the user is assured each and every inspection and test detail has been accomplished.

5.4 Wherever feasible the manufacturer must provide in-place calibration check features for permanently embedded or attached instruments such that correct functioning may be verified in place. Wherever feasible the features must permit checking both of the "zero" reading and the slope of the calibration curve.

6. DOCUMENTATION

Each instrument must be provided with an Instruction Manual that contains at least the following:

6.1 Theory of Operation

(a) Purpose of instrument

(b) Basic measuring principle of instrument

(c) Sketches and block diagrams, depicting typical applications.

(d) Limitations of system

(e) Factors that affect accuracy

(f) Specification sheet

6.2 Installation Procedure

(a) List of all materials, tools and spares required during installation.

(b) Step by step procedure for installation. Alternative procedures may be required if installation methods are dependent on application or on field conditions.

(c) Statement of necessary measurements or readings required during installation to ensure all previous installation steps have been followed correctly.

(d) Statement of all factors which should be recorded during installation for later use during data evaluation. In many cases this requirement can best be met by use of a standard form to be completed during installation.

6.3 Reading or Operating Procedure

(a) Step by step procedure for equipment set up and turn on requirements.

(b) Explanation of function of each connector and control.

(c) Cautions pertaining to personnel and equipment safety.

(d) Statement of procedure for obtaining initial (after installation) reading.

(e) Statement of procedure for obtaining readings subsequent to initial reading.

(f) Statement of construction or environmental factors which should be recorded whenever readings are made in order to permit an analysis of cause and effect.

(g) List of materials and tools required during reading procedure.

(h) Field data sheet.

(i) Sample completed field data sheet.

6.4 <u>Data Calculation and Presentation Procedure</u>

(a) Instrument calibration data

(b) Data calculation sheet

(c) Step-by-step calculation procedure

(d) Sample data calculation

(e) Alternative methods of data presentation (graphs, tables, etc.)

(f) Sample data presentation

(g) Notes on data interpretation

6.5 <u>Maintenance</u>

(a) Step-by-step acceptance test procedure to be accomplished by user on first receipt, to ensure correct functioning.

(b) Disassembly instructions to field maintenance level.

(c) Battery service instructions, if required.

(d) Procedure for check calibration in-place of permananently installed instruments, including equipment required.

(e) Procedure for check calibration of portable instruments, including equipment required. These procedures must be in such a form that check calibrations can be performed by the user or by local calibration houses, thereby avoiding the necessity of returning instruments to the factory for calibration.

(f) Frequency of required calibrations.

(g) Recommended spare parts list, including consumables.

(h) List of part numbers and manufacturers of standard parts to facilitate local procurement by user.

(i) Trouble shooting guide:

List of failure indications and probable cause

Corrective action requirements for each listed failure

Block and schematic diagrams of subsystems.

APPENDIX B

INVENTORY OF
GEOTECHNICAL INSTRUMENTS

CONTENTS

1. INTRODUCTION

1.1 Purpose and Scope.

The following inventory of geotechnical monitoring instruments has been prepared as a first step in assisting designers of monitoring programs to select appropriate devices for the task in hand. The inventory consists merely of a summary listing of instruments, and makes no attempt to evaluate between the various alternative instrument types. Certain evaluation and priority assessments for use in performance monitoring of soft ground tunnels has been made in Chapter 5, but the evaluation effort to date is incomplete. Therefore, this inventory is of limited value and is intended to serve as an interim measure pending preparation of an evaluated version. The plans for, and scope of, an evaluated version are discussed in Chapter 6.

1.2 Format of Inventory.

Instruments are grouped into five major sections, according to measured parameter:

Load measurement

Pore water pressure measurement

Earth pressure measurement

Deformation measurement

Temperature measurement

Under each major section the various commercially available instrument types are listed, together with the name of the manufacutrer or service agent for each. The final section includes an alphabetical listing of manufacturers' addresses.

The following explanatory notes will clarify instrument categorization and other notation:

(a) Strain gages are categorized under "Load Measurement" because, even though strain measurements are on occasion required as an end in themselves, the more frequent use of strain gages is as an indirect method of load measurement.

(b) Joint meters and convergence gages are categorized under "Embedded Rock Extensometers".

(c) Concrete stress cells are categorized under "Earth Pressure Measurement".

(d) The word "Numerous" in the last column indicates that there are very many manufacturers of that particular instrument type. Listings may be found in various trade journals, local industrial buyers guides, Thomas Register, Electronic Buyers' Guide (published by McGraw-Hill, N.Y.), and Instruments and Control Systems Buyers' Guide (published by Chilton Co., Philadelphia).

(e) The work "Local" in the last column indicates that the instrument can readily be assembled from parts available in most localities.

1.3 References.

Additional information describing the various instruments can be obtained from manufacturers' catalogs and from the following general references: Hanna (1973), Cording et al (1974), Gould and Dunnicliff (1971), Dunnicliff (1970), (1971) and (1972).

1.4 Omissions.

Certain manufacturers' names may not be listed alongside certain instrument types. Any such omissions are solely the result of space limitations and do not imply any inadequacy in those omitted instruments.

INVENTORY OF GEOTECHNICAL INSTRUMENTS

2. LOAD MEASUREMENT - SHEET 1

Category	Type of Instrument	Manufacturers or Service Agents
Surface and embedded strain gages	Whittemore or Demec	Huggenberger Mayes Soiltest
	Scratch	Prewitt
	Mechanical lever arm	Huggenberger
	Bonded resistance	Numerous, e.g. Automation Industries BLH Magnaflux Micro Measurements Texas Measurements
	Weldable resistance	Numerous, e.g. BLH Microdot Micro Measurements
	Unbonded resistance	Carlson Doboku Sokki Terrametrics
	Clip-on resistance	MTS
	Polyester mold resistance	Texas Measurements
	Vibrating wire	Doboku Sokki Gage Technique Geonor Maihak Telemac Terratest
	LVDT	Numerous
	Photoelastic	Chapman Lab. Horstman Photoelastic, Inc.
Load cells	Telltale	Williams Local
	Mechanical	Interfels Norseman Proceq Terrametrics

INVENTORY OF GEOTECHNICAL INSTRUMENTS

2. LOAD MEASUREMENT - SHEET 2

Category	Type of Instrument	Manufacturers or Service Agents
Load cells (continued)	Mechanical with electrical readout	Proceq
	Hydraulic	Doboku Sokki Martin Decker Terrametrics
	Bonded resistance strain gage	Numerous, e.g. BLH Brewer Dillon Doboku Sokki Engineering Lab. Equipment Gentran Houston Scientific Interface Lebow Revere Sensotec Slope Indicator Soiltest Terrametrics Texas Measurements Transducers, Inc.
	Unbonded resistance strain gage	Doboku Sokki
	Vibrating wire strain gage	Gage Technique Geonor Maihak Telemac
	Photoelastic	Horstman
	Bonded resistance strain gage for use on reinforcing bars	Doboku Sokki Structural Behavior Engineering Labs. Terrametrics
	Unbonded resistance strain gage for use on reinforcing bars	Doboku Sokki
	Vibrating wire strain gage for use on reinforcing bars	Doboku Sokki Telemac

INVENTORY OF GEOTECHNICAL INSTRUMENTS

3. PORE WATER PRESSURE MEASUREMENT - SHEET 1

Category	Type of Instrument	Manufacturers or Service Agents
Piezometers	Standpipe, including well-points (1)	Borros Engineering Lab. Equipment Geonor Geotechniques International Piezometer R & D Soil Instruments Soiltest Terra Test Local
	Standpipe, drive type (1)	Borros Engineering Lab. Equipment Geonor Soil Instruments Terra Test
	Standpipe with heavy liquid (1)	Piezometer R & D
	Standpipe with purge bubble (1)	Exactel Soil Instruments Terrametrics
	Closed hydraulic, without diaphragm (1)	Doboku Sokki Engineering Lab. Equipment Geonor Geotechniques International Huggenberger Plasticrafts Soil Instruments Soiltest Terra Test Terrametrics
	Closed hydraulic without diaphragm, drive type (1)	Geonor
	Hydraulic diaphragm (2)	Doboku Sokki Gloetzl Terrametrics
	Pneumatic (2)	Apparatus Specialties Geo-Testing Slope Indicator Soil Instruments Terra Technology

INVENTORY OF GEOTECHNICAL INSTRUMENTS

3. PORE WATER PRESSURE MEASUREMENT - SHEET 2

Category	Type of Instrument	Manufacturers or Service Agents
Piezometers (continued)	Closed hydraulic and pneumatic combination (1)	Soil Instruments Terra Technology
	Bonded resistance strain gages (2)	Doboku Sokki
	Unbonded resistance strain gages (2)	Carlson Doboku Sokki Terrametrics
	Vibrating wire strain gage (2)	Geonor Geotech Maihak Soil Instruments Telemac
	Strain gage pressure transducer (2)	Geotechniques International
	LVDT (2)	Doboku Sokki
	Full profile borehole type (2)	S.E.I.L.

NOTES:

(1) Flow piezometers, i.e. those with which the soil pore space is accessible through the measuring system.

(2) Diaphragm piezometers, i.e. those with which the pore space is separated from the measuring system by a diaphragm.

INVENTORY OF GEOTECHNICAL INSTRUMENTS

4. EARTH PRESSURE MEASUREMENT - SHEET 1

Category	Type of Instrument	Manufacturers or Service Agents
Inter-face stress cells	Hydraulic diaphragm	Doboku Sokki Gloetzl Soil Instruments
	Pneumatic	Geo-Testing Soil Instruments Terra Technology
	Bonded resistance strain gage	Doboku Sokki Gentran Mason Sensotec Soiltest Structural Instruments University of Texas Viatran
	Bonded resistance strain gage to measure normal and shear stress	Robertson Research
	Unbonded resistance strain gage	Carlson Doboku Sokki Terrametrics
	Vibrating wire strain gage	Doboku Sokki Geonor Maihak Soil Instruments
	Semi-conductor pressure transducer	Geotechniques International
	LVDT	Doboku Sokki
Earth pressure cells	Hydraulic diaphraghm	Doboku Sokki Gloetzl Soil Instruments
	Pneumatic	Geo-Testing Soil Instruments Terra Technology
	Bonded resistance strain gage	Brewer Doboku Sokki Gentran Mason Sensotec Soiltest Structural Instrumentation Viatran Waterways Experiment Station

INVENTORY OF GEOTECHNICAL INSTRUMENTS

4. EARTH PRESSURE MEASUREMENT - SHEET 2

Category	Type of Instrument	Manufacturers or Service Agents
Earth pressure cells (continued)	Unbonded resistance strain gage	Doboku Sokki
	Vibrating wire strain gage	Doboku Sokki Geonor Maihak Soil Instruments Telemac
	LVDT	Doboku Sokki
	Semi-conductor pressure transducer	Geosistemas Geotechniques International
	Inductive coils	State University of New York at Buffalo
Concrete stress cells	Hydraulic diaphragm	Doboku Sokki Gloetzl
	Unbonded resistance strain gage	Carlson Doboku Sokki Terrametrics
Stressmeters	Vibrating wire strain gage	Irad Maihak
	Photoelastic	Horstman

INVENTORY OF GEOTECHNICAL INSTRUMENTS

5. DEFORMATION MEASUREMENT - SHEET 1

Category	Type of Instrument	Manufacturers or Service Agents
Simple portable deformation gages	Graduated scale	Numerous
	Calipers	Numerous
	Micrometer	Numerous
	Dial gage	Numerous, e.g. Ames Chicago Dial Indicator Federal Fowler Huggenberger Mitotoyo
	Whittemore strain gage	Huggenberger Mayes Soiltest
	Survey tape	Numerous
	Tape extensometer	Interfels Soiltest Terrametrics
	Wire extensometer	Interfels Slope Indicator Peter Smith
	Telescoping tube or rod extensometer	Huggenberger Soiltest
Single point vertical pipe settlement gages	Surface monument	Local
	Settlement platform	Local
	Anchor post	Borros Geonor Soil & Rock Instrumentation
Multi-point vertical pipe settlement gages	Crossarm	Doboku Sokki Engineering Lab. Equipment Huggenberger Soil Instruments Soiltest Local
	Mechanical without crossarms	Slope Indicator
	Inductive coil	Soil Instruments

INVENTORY OF GEOTECHNICAL INSTRUMENTS

5. DEFORMATION MEASUREMENT - SHEET 2

Category	Type of Instruments	Manufacturers or Service Agents
Multi-point vertical pipe settlement gages (continued)	Radio transmitter	Huggenberger Idel
	Magnetic/reed switch	Doboku Sokki Engineering Lab. Equipment Soil Instruments
Single point remote settlement gages	Hose level	Soiltest Local
	Overflow type with cell at same level as readout	Engineering Lab. Equipment Soil Instruments
	Pneumatic with water column	Apparatus Specialties Geo-Testing Slope Indicator
	Pneumatic with mercury column	Soil Instruments Terra Technology
	Electrical contact with mercury	Engineering Lab. Equipment Soil Instruments
Multi-point remote settlement gages	Electrical contact with mercury	Engineering Lab. Equipment Soil Instruments
	Liquid flow	Telemac
	Precise manometer	Building Research Establishment
	Precise suspended weight	Building Research Establishment
Full profile settlement gages	Overflow type	Building Research Establishment
	Balloon type	Borros Nold
	Pressure transducer type	Roctest
	Vacuum type with pressure transducer	Geotechniques International Soil Instruments
	Inclinometer	Building Research Establishment Geo-Testing
	Two-liquid type	Soil Instruments

INVENTORY OF GEOTECHNICAL INSTRUMENTS

5. DEFORMATION MEASUREMENT - SHEET 3

Category	Type of Instruments	Manufacturers or Service Agents
Heave gages	Mechanical type without probe	Local
	Mechanical type with probing rod	Local
	Mechanical type with tape & probe	Soiltest Local
	Linear potentiometer	Slope Indicator
	All types of settlement gages	See under various settle-ment gage categories
Single point inclinometers (tiltmeters)	Plumb line	Local
	Optical bubble (Abney level)	Engineering Lab. Equipment Manufacturers of surveying equipment
	Unbonded resistance strain gage	Doboku Sokki
	Vibrating wire	Maihak Telemac
	LVDT	Doboku Sokki
	Electrolytic bubble	Hamlin Huggenberger
	Accelerometer	Structural Behavior Engineering Lab. Terra Technology
	Tidal quality resolution (electrolytic bubble, diamagnetic, horizontal pendulum)	Autonetics Earth Sciences Research Hughes Research Lab. A.D. Little Radian Corp.
Torpedo inclinometers	Simple "poor man's" type	Soil Instruments Local
	Mechanical	Pajari
	Gyroscope	Humphrey
	Punched paper disc	Eastman
	Linear resistor	Slope Indicator

INVENTORY OF GEOTECHNICAL INSTRUMENTS

5. DEFORMATION MEASUREMENT - SHEET 4

Category	Type of Instrument	Manufacturers or Service Agents
Torpedo inclinometers (continued)	Bonded resistance strain gage	Soil Instruments Soiltest Structural Behavior Engineering Lab.
	Vibrating wire strain gage	Geonor Telemac
	Accelerometer	Geo-Testing Geotechniques International Mass. Institute of Technology Slope Indicator Terra Technology U.S. Bureau of Mines
	Differential transformer	Dames & Moore
	Photographic	Eastman
	Electrolytic level	Eastman
Horizontal movement gages (other than inclinometers)	Surface monument	Local
	Plumb line	Local
	Inverted pendulum	Doboku Sokki Soil Instruments
	Tensioned wire	Doboku Sokki Local
	Inductive coil	Soil Instruments
	Radio transmitter	Huggenberger Idel
	Magnetic/reed switch	Doboku Sokki Engineering Lab. Equipment Soil Instruments
	Transverse extensometer	Slope Indicator

INVENTORY OF GEOTECHNICAL INSTRUMENTS

5. DEFORMATION MEASUREMENTS - SHEET 5

Category	Type of Instrument	Manufacturers or Service Agents
Horizontal movement gages (other than inclinometers) (continued)	Deflectometer	Doboku Sokki Eastman Interfels Slope Indicator Terrametrics
	Shear strip	Terrametrics
	Several types of embedded soil extensometers and rock extensometers.	See under various embedded extensometer categories.
Embedded soil extensometers	Rods with mechanical readout	Interfels Slope Indicator Terrametrics
	Hydraulic	Menard
	Potentiometer type with rods	Slope Indicator Soil Instruments
	Vibrating wire strain gage with rods	Geonor
	Vibrating wire strain gage with wires	Telemac
	Inductive coils (soil strain gage)	Bison Ecotec
Embedded rock extensometers	Rods with mechanical readout	Interfels Slope Indicator Soiltest Terrametrics Williams
	Wires with mechanical readout	Engineering Lab. Equipment Huggenberger Interfels Peter Smith Structural Behavior Engineering Lab. Terrametrics
	Rods with mechanically driven drum recorder	Davis Terrametrics
	Wires with mechanically driven drum recorder	Geolograph

INVENTORY OF GEOTECHNICAL INSTRUMENTS

5. DEFORMATION MEASUREMENT - SHEET 6

Category	Type of Instrument	Manufacturers or Service Agents
Embedded rock extensometers (continued)	Wires with bonded resistance strain gage	Huggenberger Terrametrics
	Rods with unbonded resistance strain gage	Doboku Sokki Terrametrics
	Rods with vibrating wire strain gage	Geonor Maihak
	Wires with vibrating wire strain gage	Telemac
	Rods with linear potentiometer	Interfels Slope Indicator
	Wires with potentiometer readout	Interfels Slope Indicator
	Rods with inductive sensors	Interfels
	Rods with warning light	Soiltest
	Rods with LVDT	Structural Behavior Engineering Lab.
	Wires with LVDT	Doboku Sokki Structural Behavior Engineering Lab.

INVENTORY OF GEOTECHNICAL INSTRUMENTS

6. TEMPERATURE MEASUREMENT - SHEET 1

Category	Type of Instrument	Manufacturers or Service Agents
Temperature sensors	Mercury thermometer	Numerous
	Bi-metal thermometer	Numerous, e.g. Dresser Marsh Weksler Weston
	Thermistor	Numerous, e.g. Atkins Conax Edison Fenwal Gentran Micro-Measurements Soiltest Sostman Telemac Terratest Weather Measure
	Thermocouple	Numerous, e.g. Alnor BLH Conax Fenwal Gentran Gordon Honeywell Marlin Microdot Thermetrics
	Vibrating wire strain gage	Maihak Telemac
	Non-inductive copper coil	Carlson Doboku Sokki Terrametrics

7. ADDRESSES OF MANUFACTURERS AND SERVICE AGENTS

Alnor Instrument Co., 420 N. LaSalle St., Chicago, Illinois 60610

B.C.Ames Co., 131 Lexington St., Waltham, Massachusetts 02154

Apparatus Specialties Co., 122 Saddle River, New Jersey 07458

Atkins Technical, Inc., P.O. Box 14405, University of Florida Station, Gainesville, Florida 32601

Autonetic Division, North American Rockwell, 3370 Miraloma Avenue, Anaheim, California 92803

Automation Industries, Inc., Shelter Rock Road, Danbury, Connecticut 06810

Bison Instruments, Inc., 3401 48th Avenue North, Minneapolis, Minnesota 55429

BLH Electronics, Inc., Waltham, Massachusetts 02154

Borros Co., Ltd., Box 3063, S-17103 Solna 3, Sweden
U.S. supplier: Soil and Rock Instrumentation, Inc.

Brewer Engineering Laboratories, Inc., P.O. Box 288, Marion, Massachusetts 02738

Building Research Establishment, Building Research Station, Garston, Watford, WD2 7JR, England.

Carlson Instruments, 1203 Dell Avenue, Campbell, California 95008

Chapman Laboratories, Inc., Box 207, West Chester, Pennsylvania 19380

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Conax Corporation, 2300 Walden Avenue, Buffalo, New York 14225

Dames & Moore, 445 South Figueroa St., Los Angeles, California

John Davis & Sons, Ltd., P.O. Box 38, Alfreton Road, Derby, England.

W.C. Dillon & Co., Inc., 14620 Keswick St., Van Nuys, California 91407

Doboku Sokki Center Co., Ltd., No. 780 Nase-Cho, Totsuka-ku, Yokohama-shi, Kanagawa-ken, Japan. U.S. supplier - Terrametrics, Inc.

Dresser Industries, Inc., Stratford, Conn. 06497

Eastman International Co., P.O. Box 1680, Denver, Colorado 80201

Earth Science Research, 133 Mount Auburn St., Cambridge, Massachusetts 02138

Ecotec Corp., 14 Charles St., Needham Heights, Massachusetts 02194

Edison Instrument Division, McGraw-Edison Co., 2 Babcock Place, West Orange, New Jersey 07051

Engineering Laboratory Equipment Ltd., Woodcock Hill, Harefield Road, Rickmansworth, Hertfordshire, England U.S. Supplier: Seelec, Inc., 999 N. Main St., Glen Ellyn, Illinois 60137

Exactel Instrument Co., 89 Pioneer Way, Mountain View, California 94040

Federal Products Corporation, 1144 Eddy St., Providence, R.I. 02901

Fenwal, Inc., Ashland, Massachusetts.

Fred V. Fowler Co., 875 No. Virgil Avenue, Los Angeles, California 90029

Gage Technique Ltd., P.O. Box 30, Trowbridge, Wilts, England.
U.S. Supplier - Terrametrics, Inc.

Gentran, Inc., 928 Thompson Place, International Science Center, Sunnyvale, California 94086

Geolograph Mining Division, 33 N.E. 27th St., P.O. Box 25246, Oklahoma City, Oklahoma 73125

Geonor, Grini Molle, P.O. Box 99, Roa, Oslo, 7, Norway
U.S. Suppliers: Slope Indicator Co., Soil & Rock Instrumentation, Inc.

Geosistemas, S.A., Calle Oriente 233 No. 36, Mexico 9, D.F. Mexico.

Ing. Fa Geotech Co. Ltd., Värslevägen 39 S-43600, Askim, Sweden.

Geotechniques International, Inc., P.O. Box 553, Marblehead, Massachusetts 01945

Geo-Testing, Inc., P.O. Box 959, San Rafael, California 94902

Franz Gloetzl, D-7501 Forchheim, Baumesstechnik, West Germany
U.S. Supplier: Terrametrics, Inc.

Claud S. Gordon Co., 5710 Kenosha St., Richmond, Illinois. 60071

Hamlin, Inc., Lake and Grove Sts., Lake Mills, Wisconsin 53551

Honeywell, Industrial Division, Fort Washington, Pennsylvania 19034

Horstman, Ltd., Locksbrook Road, Bath, England
U.S. Supplier: Terrametrics, Inc.

Houston Scientific Industries, Inc., 4202 Directors Row, Houston, Texas 77018

A.G.Huggenberger, Ackersteinstrasse 119, Zurich, Switzerland

Hughes Research Laboratories, 3011 Malibu Canyon Road, Malibu, California 90265

Humphrey, Inc., 9212 Balboa Avenue, San Diego, California 92123

Dr. Ing. Heinz Idel, Potthoffs Borde 15, 43 Essen, W. Germany
U.S. Supplier: Terrametrics, Inc.

Interface, Inc., 7210 East Acoma, Scottsdale, Arizona 85260

Interfels, Zweigniederlassung, Bentheim, Germany
North American Supplier: Roctest

Irad, Box 31, Lyme, New Hampshire 03768

Lebow Associates, Inc., 1728 Maplelawn Road, Troy, Michigan 48084

Arthur D. Little, Inc., Acorn Park, Cambridge, Massachusetts 02140

Magnaflux Corp., 7328 W. Lawrence Avenue, Chicago, Illinois 60656

H. Maihak, 2000 Hamburg, 39 Semper St., Hamburg, West Germany
U.S. Supplier: Ampower Corp., 1 Marine Plaza, North Bergen, New Jersey 07047

Marlin Manufacturing Corporation, 12404 Triskett Road, Cleveland, Ohio. 44111.

Martin-Decker Co., 1928 South Grand Avenue, Santa Ana, California 92705

Marsh Instrument Co., Skokie, Illinois 60076

Mason Research Consultants, 1550 Dominion Avenue. Sunnyvale, California 94087

Massachusetts Institute of Technology, Civil Engineering Dept., Cambridge, Massachusetts 02140

W.H.Mayes & Sons Ltd., Vansittart Estate, Arthur Road, Windsor, Berkshire, England.

Menard, Techniques Louis, France. U.S. Supplier: Terrametrics, Inc.

Microdot, Inc., 19535 East Walnut Drive, City of Industry, California 91744

Micro-Measurements, Box 306, 38905 Chase Road, Romulus, Michigan 48174

Mitutoyo Manufacturing Co., Ltd., Tokyo, Japan
U.S. Supplier: MTI Corp., 11 East 26th St., New York, N.Y. 10010

MTS Systems Corp., P.O. Box 6112, Minneapolis, Minnesota, 55424.

Walter Nold Co., 24 Birch Road, Natick, Massachusetts 01760

Norseman, Ltd., Uxbridge Road, Stoke Poges, Slough, Bucks SL2 4 QD, England.

Photoelastic, Inc., 67 Lincoln Highway, Malvern, Pennsylvania.

Plasticrafts, Inc., 2800 N. Speer Boulevard, Denver, Colorado 80211

Prewitt Associates, Box 365, Lexington, Kentucky 40501

Proceq SA, Riesbachstrasse 57, CH-8034, Zurich 8, Switzerland
U.S. Supplier: Soil & Rock Instrumentation, Inc.

Radian Corporation, 8500 Shoal Creek Boulevard, P.O. Box 9948, Austin, Texas 78766

Revere Electronic Division, 845 North Colony Road, Wallingford, Connecticut 06492

Robertson Research International Ltd., 'TY' N-Y-COED',Llanrhas, Llandudno
North Wales, LL30 15A, England.

Roctest, Limited, 435, Norman, Ville St. Pierre, Canada.

S.E.I.L. (Société D'Études Industrielles En Laboratoire), 24 Rue Du R.P. Christian-Gilbert, 92 Asnieres, Paris, France.

Sensotec, Inc., 1400 Holly Avenue, Columbus, Ohio 43212

Slope Indicator Co., 3668 Albion Place, North, Seattle, Washington 98103

Peter Smith Instrumentation Limited, Gosforth Industrial Estate, Newcastle Upon Tyne NE3 1XF, Gosforth, England. North American Supplier: Roctest

Soil and Rock Instrumentation, Inc., 30 Tower Road, Tower Office Park, Newton Upper Falls, Massachusetts 02164

Soiltest Inc., 2205 Lee St., Evanston, Illinois 60202

Sostman Division - YSI, P.O. Box 279, Yellow Springs, Ohio 45387

State University of New York at Buffalo, Department of Civil Engineering, Parker Engineering Building, Buffalo, New York 14214

Structural Behavior Engineering Laboratories, P.O. Box 9727, Phoenix, Arizona 85020

Structural Instrumentation, 4611 South 134th Place, Tukwila, Washington 98188

Telemac International, Inc., 5450 Cote des Neiges, Montreal 249 P.Q., Canada

Terrametrics, Inc., 16027 West 5th Avenue, Golden, Colorado 80401

Terra-Technology Corporation, 3018 Western Avenue, Seattle, Washington 98121

Terra Test, 43 Baywood Road, Rexdale, Ontario, Canada.

Texas Measurements, Inc., 2404 Wayside Drive, Bryan, Texas 77801

Thermetrics Division, 630 East Young St., Santa Ana, California 92705

Transducer, Inc., 12140 E. Rivera Road, Whittier, California 90606

U.S. Bureau of Mines, Denver Mining Research Center, Denver, Colorado.

University of Texas at Austin, Center for Highway Research, Austin, Texas.

Viatran Corp., 1720 Military Road, Buffalo, New York 14217

Waterways Experiment Station, U.S. Corps of Engineers, P.O. Box 631 Vicksburg, Mississippi. 39180

Weather Measure Corp., P.O. Box 41257, Sacramento, California 95841

Weksler Instruments Corp., 80 Mill Road, Freeport, New York 11520

Weston Instruments, Inc., 614 Frelinghuysen Avenue, Newark, New Jersey 07114

Williams Form Engineering Corp., 1501 MadisonAvenue S.E., Grand Rapids, Michigan 49507

APPENDIX C

MONITORING SYSTEM PLANNING CHECKLIST

MONITORING SYSTEM PLANNING CHECKLIST

1. Define the Problem

   Project type
   Soil and groundwater conditions
   Status of nearby structures
   Potential problems
   Benefits of monitoring

2. Define the Purpose of the Instrumentation

   Diagnostic: To verify suitability of construction techniques
   To diagnose the specific nature of an adverse event
   To verify continued satisfactory performance
   To verify adequacy of design

   Predictive: To permit a prediction of behavior later on at the same job.

   Legal: To establish a bank of data for possible use in litigation

   To demonstrate a constractor's compliance with contract requirements

   Research: To advance the state-of-the-art by providing better future design data

3. Select Monitoring Parameters

   Settlement or heave (surface or sub-surface)
   Horizontal movement (surface or sub-surface)
   Relative movement (strain, convergence, differential settlement, liner distortion)
   Pore water pressure (groundwater level)
   Load or stress
   Earth pressure (total or contact)
   Tilt
   Temperature

4. <u>Make Predictions of Behavior and Define Specific Instrumentation Needs</u>

Range
Accuracy
Duration of readings
Frequency of readings
Data evaluation schedule

5. <u>Assign Responsibilities</u>

Who will procure the instruments?
Who will install the instruments?
Who will monitor the instruments?
Who will maintain the instruments?
Who will process the data?
Who will analyze the data?
Who will decide on implementation?
Who will implement?

6. <u>Select Instruments, Components and System</u>

General Criteria

- Select each part of the system with equal care
- Will it achieve objective?
- Maximum simplicity
- Maximum durability in installed environment
- Minimum susceptibility to vandalism
- Appropriate accuracy, range, longevity
- Good past performance record
- Minimum cost (to furnish, install, read, process)
- Maximum environmental stability
- Calibration can be verified after installation
- Consistent with skills of available personnel as in 5. above
- Minimum interference to construction while installing and reading
- Minimum falsification of measured parameter

Settlement or Heave

- Surface monument
- Optical survey
- Settlement platform
- Subsurface anchor
- Mechanical probe rod
- Mechanically latching torpedo subsurface settlement gage

- Electrical torpedo subsurface settlement gage
- Hose level
- Single point remote settlement cell
- Multi point remote settlement cells
- Full profile settlement gage
- Other "Relative Movement" device
- Other

Horizontal Movement

- Surface survey point
- Optical survey
- Inclinometer, precise type
- Inclinometer, less precise type
- Electrical torpedo
- Deflectometer
- Shear strip
- Other "Relative Movement" device
- Other

Relative Movement

- Graduated scale
- Calipers
- Micrometer
- Dial gage
- Mechanical strain gage
- Survey tape
- Portable tape extensometer
- Portable wire extensometer
- Portable telescoping tube or rod extensometer
- Embedded rod or wire extensometer with mechanical readout
- Embedded rod or wire extensometer with electrical readout
- Soil strain gage
- Other

Pore Water Pressure (Groundwater level)

- Standpipe piezometer (or wellpoint)
- Double tube hydraulic piezometer
- Hydraulic diaphragm piezometer
- Pneumatic piezometer
- Combination double tube hydraulic and pneumatic piezometer
- Electrical pressure transducer piezometer
- Vibrating wire strain gage piezometer
- Other

Load or Stress

- Mechanical strain gage
- Resistance strain gage
- Vibrating wire strain gage
- Photoelastic strain gage
- Mechanical load cell
- Hydraulic load cell
- Resistance strain gage load cell
- Vibrating wire strain gage load cell
- Photoelastic load cell
- Other

Earth Pressure

- Hydraulic diaphragm cell
- Pneumatic cell
- Bonded resistance strain gage cell
- Electrical pressure transducer cell
- Vibrating wire strain gage cell
- Inductive coil cell
- Other

Tilt

- Plumb line
- Optical bubble
- Vibrating wire strain gage
- Electrolytic bubble
- Accelerometer
- Tidal quality resolution tiltmeter
- Other

Temperature

- Mercury thermometer
- Bi-metal thermometer
- Thermistor
- Thermocouple
- Vibrating wire strain gage thermometer
- Non-inductive coil thermometer
- Other

7. Determine What Factors May Influence Measured Data (to permit an analysis of cause and effect)

   Detailed record of all construction particulars, progress and other data

Incidence of any observed distress or unusual event
Environmental factors which may, in themselves, affect monitored data, e.g. temperature, nearby construction activities.

8. Plan Procedures for Ensuring Reading Correctness

Consider necessary redundancy
Consider duplicate measuring system
Plan how instruments will be calibrated and corrected for environmental effects
Consider possibility of feature to check-calibrate in place

9. Determine a Numerical Value of Deviation from Anticipated Performance at which the Engineer Should:

Be concerned
Press the panic button

10. Plan Instrument Layout

How many?
Where?

11. Write Instrument Procurement Specifications

12. Plan Installation

Write installation specifications
Prepare field data sheet for recording details of installation
Examine every detail of the planned installation procedure and think through alternative methods in the event problems arise
Make detailed list of all materials and tools required

13. Plan Procedures Subsequent to Installation

Plan monitoring arrangements
Prepare field data sheets
Plan maintenance arrangements
Plan data processing arrangements
Plan analytical procedures
Plan remedial measures (in the event data indicates adverse event) or other methods of implementation, and forewarn all concerned parties

14. Subsequent Activities

Procure instrument
Install instruments
Monitor instruments
Maintain instruments
Process data
Implement

APPENDIX D

ANNOTATED OUTLINE OF MANUAL 1

USES AND BENEFITS OF SOFT GROUND TUNNELING INSTRUMENTATION

Manual of Soft Ground Tunnel Monitoring Instrumentation for Planners and Designers

1. SCOPE AND PURPOSE

(To whom manual is addressed, initial background material, summary of contents, interest raisers)

2. THE NEEDS AND BENEFITS OF MONITORING

2.1 Basic Concerns

Functional Requirements
Construction Safety
Environmental Concerns
Minimizing Costs
Legal and Contractual Concerns
Advancing the State-of-the-Art

2.2 Functions of Monitoring

Diagnostic Functions
Predictive Functions
Legal Functions
Research Functions
(Text in part from Dunnicliff & Schmidt, 1974, and Chapters 1 and 3 of this report)

2.3 Benefits of Monitoring

Avoidance of Underpinning
Reduction of Environmental Effects
Construction Costs
Safety
Research
(Text in part from Dunnicliff & Schmidt, 1974, and Chapter 3 of this report)

2.4 The Costs of Monitoring

3. SIGNIFICANT TUNNELING PROBLEMS IN SOIL

3.1 Introduction

3.2 Typical Tunneling Procedures

3.3 Effects of Tunneling

3.4 Safety Hazards

3.5 Effects of Ground Movements on Existing Structures (Text may be nearly identical to Chapter 2 of this report)

4. SELECTION OF MONITORING PARAMETERS AND INSTRUMENTATION HARDWARE

4.1 Engineering Criteria for Parameters Selection

4.2 Groundwater Parameters

4.3 Ground Deformations

4.4 Observations on Existing Structures

4.5 Soil-Structure Interaction Monitoring

4.6 Progress Monitoring

4.7 Systematic Guide to Parameter Selection, Check Lists (Text in part from Schmidt & Dunnicliff, 1974, Chapters 4 and 5 of this report)

5. A SYSTEMATIC APPROACH TO TUNNEL CONSTRUCTION MONITORING

5.1 Tasks and Sequences

5.2 Planning and Design Processes

5.3 Implementation of Monitoring Results

5.4 Contractual Setups, Delegation of Responsibilities (Text from Chapter 4 of this report plus new text)

6. CONTRACT DOCUMENTS

6.1 Instrument Procurement and Installation Specifications (Refer to Manual 2)

6.2 Favorable Contractual Setups (The Need for Incentives)

6.3 Distribution of Responsibilities and Duties

6.4 Concentration on Technical Project Control (i.e. Efficient control of contractor's performance, sample specifications, etc.) (New text)

7. DATA PROCESSING, INTERPRETATION AND IMPLEMENTATION

7.1 Data Acquisition and Handling
(Text in part from Chapter 7 of this report)

7.2 Methods of Ground Movement Interpretation and Prediction
(Text in part from Chapter 2 of this report, Schmidt, 1974)

7.3 Use of Other Monitoring Data

7.4 Project Control

7.5 Computerized Systems

8. REFERENCES OR BIBLIOGRAPHY

Listed by Topic

APPENDIX E

ANNOTATED OUTLINE OF MANUAL 2

SELECTION AND USE OF INSTRUMENTATION FOR MONITORING PERFORMANCE OF SOFT GROUND TUNNELS

1. INTRODUCTION

1.1 Justification for Manual

Content based on brief summary of Report Chapters 1 through 4, and on Dunnicliff and Schmidt (1974).

1.2 Purpose of Manual

To provide guidance and information concerning the utilization of instrumentation to monitor the performance of soft ground rapid transit tunnels during construction. To provide criteria, standards, directives, etc., for use by engineers. To enhance the practice of monitoring through better education and training of users.

1.3 Scope of Manual

Presentation of guidance regarding the selection of instrumentation hardware for monitoring of specific parameters, and guide specifications for instrument procurement and installation. Maintenance of instruments, data acquisition and reporting are also included. The manual contains checklists, instrument inventories, and other practical tools for the use of the instrumentation program designers and specification writers.

1.4 To Whom Addressed

Geotechnical engineers responsible for project design

Specification writers responsible for preparation of construction documents

Geotechnical engineers responsible for supervision of construction

Engineers and technicians responsible for instrument installation, maintenance and data handling (including contractor's personnel).

1.5 Review Process

The manual will first be presented to users as a working draft. After some use it is anticipated that review, updating and rewriting of chapters may be desirable. When the manual has been generally accepted by the professions and authorities, it may be possible to assign standard or directive status to some or all chapters.

1.6 Summarize Manual 1

Elaborate on aspects relevant to the geotechnical engineer and technician, which are:

(a) Needs for monitoring

(b) Benefits of monitoring

(c) Selection of parameters to monitor

(d) Implementation of monitoring results

Use will also be made of the content of Dunnicliff and Schmidt (1974).

2. STEPS IN DESIGNING A PROGRAM TO MONITOR PERFORMANCE

2.1 Intent of Chapter

Many monitoring programs fail in their purpose because the design engineer does not approach the program design in a logical sequence. The normal sequence of engineering design includes certain logical steps, which in part are:

(a) Definition of the design objective

(b) Formulation of alternative feasible designs

(c) Selection of the most appropriate design, based on rational judgments as to the suitability of each alternative in conjunction with the cost of each.

Frequently, the design of an instrumentation program is not subjected to this sequence. Many times the outcome is a disappointment to all concerned, and all too often blame is directed at the instruments themselves, resulting in general disenchantment with the usefulness of instrumentation as a working engineering tool. This chapter presents necessary steps in the design process, and includes sufficient guidelines to enable the designer to make all necessary design decisions.

2.2 Steps in Design and Planning process

The text of this section will be based on Chapter 4 of the Report and on the checklist presented in Appendix C.

3. DEFINITION OF TERMS

Movement

Load

Stress

Strain

Modulus

Pore Pressure

Earth Pressure

Resistance

Inductance

Capacitance

Frequency

Other electrical terms

Accuracy

Precision, Reproducibility, Repeatability

Sensitivity

Error

Bias

4. TYPES OF SENSING SYSTEMS

Descriptions and schematic diagram in clear and simple terms:

Quarter, half and full Wheatstone bridge

Linear potentiometer

Linear resistor

LVDT

Inductive coil

Semiconductor sensor

Piezoelectric sensor

Piezoresistive sensor

Variable reluctance transducer

Bonded resistance strain gage

Weldable resistance strain gage

Unbonded resistance strain gage

Vibrating wire strain gage

Null-balance accelerometer

Photoelastic gage

Purge bubble

Pneumatic diaphragm

Hydraulic diaphragm

Various pressure balance systems

Optical bubble

Electrolytic bubble

Diamagnetic sensor

Horizontal pendulum

Gyroscope

Bi-metal thermometer

Non-inductive copper coil

Thermistor

Thermocouple

Magnet/reed switch

5. GROUNDWATER PARAMETERS

5.1 Introduction to monitoring of groundwater level, dewatering progress and infiltrating water; briefly restate needs and benefits.

5.2 Accuracy and measuring range required.

5.3 Commercially available instruments (refer to Appendix B). Preferred instruments, with reason for preference, description of each and schematic diagrams as necessary. Advantages, limitations and accuracy of each preferred instrument, in tabular form. Recommendations to assist in making final selection of instrument. Guide specification for instrument procurement, refer to Appendix A.

5.4 Installation specifications and procedures for each preferred instrument, with list of necessary materials and tools. Guidelines for instrument layout.

5.5 Reading procedures, data sheets, data handling, computations and plotting format for each instrument. Critical monitoring times. Factors that may influence measured data.

5.6 Maintenance of instruments.

5.7 Guidelines for implementation of monitoring results.

A substantial part of the material for this chapter will be derived from the body of this report, Chapters 5, 7, 8 and Appendix B, and from Dunnicliff and Schmidt (1974).

6. GROUND DEFORMATIONS

6.1 Monitoring of surface settlement, subsurface settlement, surface horizontal movement, subsurface horizontal movement, tail void encroachment, and ground heave.

6.2 - 6.7 Format similar to 5.2 - 5.7.

A substantial part of the material for this chapter will be derived from the body of this report, Chapters 5, 7, 8 and Appendix B, and from Dunnicliff and Schmidt (1974).

7. OBSERVATIONS ON EXISTING STRUCTURES

7.1 Monitoring "before and after conditions," settlements, horizontal displacements and strains of structures and utilities, tilt.

7.2 - 7.7 Format similar to 5.2 - 5.7

A substantial part of the material for this chapter will be derived from the body of this report, Chapters 5, 7 and Appendix B, and from Dunnicliff and Schmidt (1974).

8. SOIL-STRUCTURE INTERACTION IN CUT-AND-COVER TUNNELS

8.1 Monitoring structural loads and deformations in cross-lot bracing, tie-backs, walers, soldier piles and walls, earth and water pressures on walls.

8.2 - 8.7 Format similar to 5.2 - 5.7.

A substantial part of the material for this chapter will be derived from the body of this report, Chapters 5, 7 and 9, and from Dunnicliff and Schmidt (1974).

9. SOIL-STRUCTURE INTERACTION IN BORED TUNNELS

9.1 Monitoring location and distortion of tunnel linings, earth and water pressures on linings, thrusts and stress in linings.

9.2 - 9.7 Format similar to 5.2 - 5.7.

A substantial part of the material for this chapter will be derived from the body of this report, Chapters 5 and 7, and from Dunnicliff and Schmidt (1974).

10. TEMPERATURE

10.1 Needs for measuring temperature .

10.2 - 10.7 Format similar to 5.2 - 5.7.

Part of the material for this chapter will be derived from the body of this report Appendix B. Much of the content will be new material.

11. PROGRESS DATA

11.1 Need for monitoring progress data.

11.2 Progress data for bored tunnels.

11.3 Progress data for cut-and-cover tunnels.

A substantial part of the material for this chapter will be derived from the body of this report Chapter 4, Section 4.3 and from Dunnicliff and Schmidt (1974).

APPENDIX A. QUALITY CONTROL SPECIFICATION FOR INSTRUMENT PROCUREMENT

A.1 Introduction

A.2 Scope

A.3 Mechanical Requirements

A.4 Electrical Requirements

A.5 Factory Calibration and Quality Assurance Requirements

A.6 Documentation

This material will be taken from Appendix A of this report.

APPENDIX B. INVENTORY OF GEOTECHNICAL MONITORING INSTRUMENTS

B.1 Introduction

B.2 Load Measurement

B.3 Pore Water Pressure Measurement

B.4 Earth Pressure Measurement

B.5 Deformation Measurement

B.6 Temperature Measurement

B.7 Addresses of Manufacturers and Service Agents

This material will be taken from Appendix B of this report, with evaluations as discussed in Section 6.4.

BIBLIOGRAPHY

List of references in alphabetical order of author name, each numbered in sequence.

Categorized list, according to subject, listing reference numbers in each category. Probable categories:

General

Groundwater monitoring

Ground Deformation Monitoring

Observations on Existing Structures

Soil-Structure Interaction

Temperature

INDEX

Alphabetical index of subject matter and page number

APPENDIX F

TECHNICAL SPECIFICATION

FOR

COMPUTER PROGRAM

ENTITLED

DATA PROCESSING SYSTEM FOR

SOFT GROUND TUNNEL

CONSTRUCTION MONITORING

(DAPSOG)

CONTENTS

1. GENERAL REQUIREMENTS

The contractor selected for the writing, verification, debugging and documentation of the DAPSOG program shall be responsible for the following tasks:

(a) Formulation of a logical and efficient system of data input, storage, analysis and output based on the general requirements and specific details contained herein.

(b) Writing of the complete computer program with all specified options and control features, using Fortran IV and specifically intended for use by an IBM 1130 computer or equivalent.

(c) Complete debugging of program, using reasonable data sets in all likely variations.

(d) Preparation of complete documentation, including a system's manual, showing the detailed program logic to allow future changes by others, and a user's manual, written for the noncomputer-oriented user.

(e) Deliver the complete source program on cards, with a reproducible copy of the system's and user's manuals.

The contractor shall employ at least one qualified systems analyst and one qualified programmer to accomplish these tasks. The responsibilities associated herewith shall be with one person designated in the contractor's proposal; this person shall not be substituted without prior approval.

The contractor shall consult with (name/organization) at regular intervals during the work and whenever significant questions or problems arise; (name/organization) will provide guidance where needed, will supply data sets for testing and verification, and will inspect the work for quality and performance prior to delivery.

2. BACKGROUND AND GENERAL PROGRAM DESCRIPTION

The DAPSOG program is intended to provide convenient storage of data from soft ground tunnel construction monitoring, and to provide selected data retrieval in any one of several optional formats, for interpretive and diagnostic use by the inspecting engineers and the contractor. Certain interpretive functions will be incorporated in the program itself.

Briefly, the program will handle data of the following nature:

(a) Basic Tunnel Data: Geometrical configurations, i.e. defined tunnel and shield dimensions, vertical alignment data for use in analysis and output, horizontal alignment data for informative output only.

(b) Tunnel Progress Data: Location of shield front as input at regular intervals; indications of interruptions of progress; commentaries regarding significant incidents, maximum 1,000 entries anticipated. Available for analysis and output.

(c) Surface Settlement Data: Data from numerous surface settlement points, up to 2,000 for a project, along the tunnel centerline and at some distance along right angles to the centerline. Data for individual points may reach 50, input at various times during the project duration. For output singly or in a variety of grouped options, and for analysis.

(d) Deep Settlement Data: Data from deep settlement points of simple extensometer type (up to 200 for a project, up to 25 readings per point), located mainly above the centerline of the tunnel but occasionally elsewhere. For output singly or in combinations.

(e) Horizontal Displacement Data: Data from displacement of points, principally along baselines at right angles to the centerline; up to 1,000 individual points, up to 25 readings per point. For output singly or combined, for analysis.

(f) Groundwater Data: Data from piezometers or observation wells of standpipe or electrical type. Up to 100 on a project, up to 50 readings each. For output singly or combined.

Additional types of data that may be included in the program at a later time are:

(g) Inclinometer Data: Data indicating horizontal displacement with depth, measured by torpedo inclinometer or by fixed inclinometers, at locations generally off the centerline.

(h) Deep Settlement Data: From instruments other than simple extensometers.

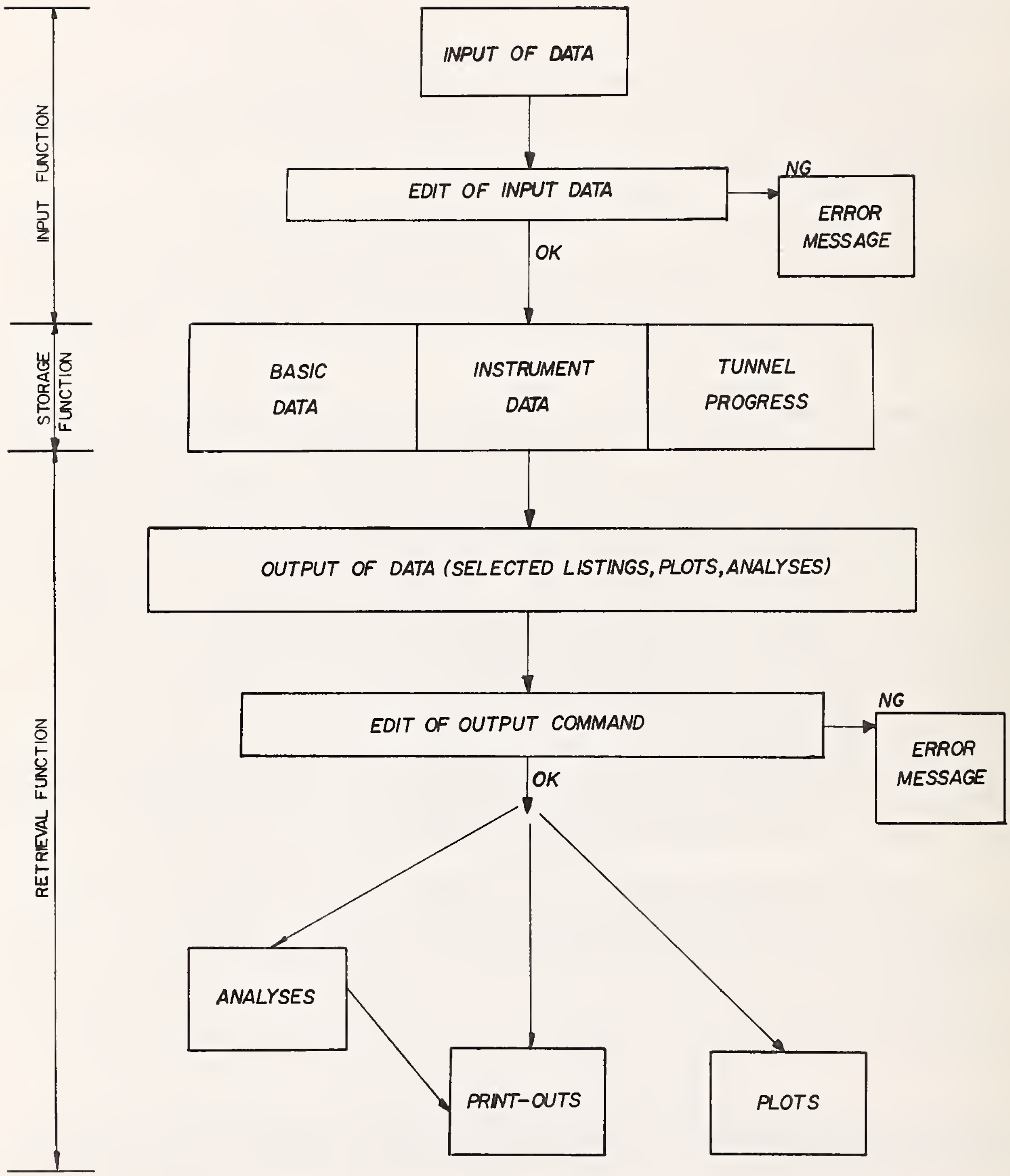


Figure F-1. DAPSOG System - Flow Diagram

(i) As-Built Tunnel Data: Actual as built centerline location, horizontal and vertical diameter.

(j) Tunnel Distortions With Time: Changes in horizontal and/or vertical diameter with time after construction.

The Basic Tunnel Data have a format somewhat similar to common programs for analyzing alignment geometrics, and a perusal of such programs will be an aid.

While the DAPSOG program is not at this time intended to aid the contractor in shield steering and geometry control, facilities of this nature may be fitted in at a later time.

A rough system flow sketch is shown on Fig. F-1.

3. FACILITIES AND OPERATING MODES

Although future versions of the DAPSOG program may be fitted to time-sharing interactive modes, this version shall be designed for batch operation but with full attention to the need for fast turn-around time and data retrieval.

The program shall be written in FORTRAN IV and be adapted for use on IBM 1130 equipment or equivalent; it is estimated that a minimum of three disk storage cartridges are required. The input will be through cards, and retrieval shall be printed in tabular form, plotted by line printer, or plotted on incremental drum plotter at the user's option.

Specific file capacity shall be available in each designated file, but provisions shall be made for simple file expansion of individual data files, should the need arise during use.

It must be considered that the program and hardware set-up may service several construction projects simultaneously; hence, provisions must be made to avoid inadvertent access to the wrong files.

Access to a project file shall be through the use of a command employing a user code name, the program name DAPSOG, and a project name. For security reasons, opening of a new project data file shall be performed only by the resident data processing specialist.

Last card of a series of data input or commands shall place all data in respective files and close the DAPSOG file until next access command.

4. DATA INPUT - GENERAL

Input will be on cards. The contractor will work out appropriate card formats and provide input forms. It is suggested that job names be six alphanumeric characters or less, beginning with a letter.

Instrument identifications (data collection points) shall be integer numbers from 1 to 30,000. Since input and output for any instrument (data point) is always associated with instrument type indication, the same identification or name may be used for several instrument types.

Command words for use on cards shall be six characters (letters) or less, and a perfect match shall be required for execution.

Numeric input values currently considered are almost all dimensions. For simplicity, the first version of DAPSOG will consider only dimensions in feet. A feature may later be added by which the addition of *IN* after a numeric input will allow conversion from inches to feet before storage.

Numeric input may have any mathematical format, integer, decimal point, exponent form, acceptable by the computer; they may be positive or negative. If sign is left out, positive is assumed.

Dates must be valid (i.e. on calendar), and have the format month/day/year. No spaces are allowed, and each number must be a two digit integer (e.g. 02/01/74).

Time arguments must be valid military time in the format hour.minutes from 0.00 to 23.59. If time arguments are omitted, 0.00 will be assumed by the program.

Arguments indicating a time period for output selection can have the following suggested format:

$$\textit{FROM TIME} \left\{ \begin{matrix} \textit{BEGIN} \\ \textit{date (,time)} \end{matrix} \right\} \textit{TO} \left\{ \begin{matrix} \textit{END} \\ \textit{date (,time)} \end{matrix} \right\};$$

if this argument is omitted, time from beginning to end, i.e. all data, will be assumed.

Arguments indicating stationing for output selection can have the following suggested format:

$$FROM\ STAT \begin{Bmatrix} BEGIN \\ Station \end{Bmatrix} TO \begin{Bmatrix} END \\ Station \end{Bmatrix};$$

if this argument is omitted, stationing from beginning to end of data file will be assumed.

Before data are accepted for storage, they must be checked for acceptability: command words must match; data, dates, times and stations must be of appropriate format; these items must also be checked for consistency - e.g. dates and times of monitoring data must be after initial date of instrument, stationing must be between first and last station of project, etc. -; no data may be accepted unless a file has been generated for the named instrument; no data may be accepted for date and time for which data are already stored.

Certain checks of reasonableness may be instituted. For example, data showing a ground movement of more than one foot or a groundwater lowering of more than three feet between consecutive readings may be accepted only with an output warning that the data may be erroneous.

In any instance, when data are not accepted, output shall show which data are not accepted and for what reason, while the remaining card deck of data is input.

Contractor shall further examine the needs and possibilities for data verification and associated error messages.

If data are erroneously entered, a delete command shall enable removal of the specifically identified (by type, name, date (,time) data,) and altered data may be reentered by next following card.

After editing of input data, all input data accepted shall be output for verification as input and as stored, and all input not accepted shall be output with appropriate error messages.

Monitoring data are not necessarily received and entered in a chronological order. It is desirable, however, that they be stored chronologically. Therefore, a sorting mechanism shall be provided that will check the date and time of the last entered data in a particular file and cause rearrangement of data in chronological order if the new data are older than last stored data.

5. DATA INPUT - BASIC DATA

All data are to be referred to a simple basic coordinate system, using the horizontal trace of the tunnel centerline as the x-axis, and the tunnel stationing as the x-coordinate, irrespective of the curvature of the tunnel. The y-axis is horizontal, is positive to the left, looking upstation, and has its zero point at the x-axis. The z-axis is vertical and positive upwards, using elevations referred to a single common elevation base as the z-coordinate (see Fig. F-2). This is an ordinary right handed coordinate system.

It is presumed that stationing is continuous from one end of the project or section to the other; however, stationing may not begin from station zero, and tunneling may proceed in a down-station direction.

Tunnel geometry data shall be entered as follows:

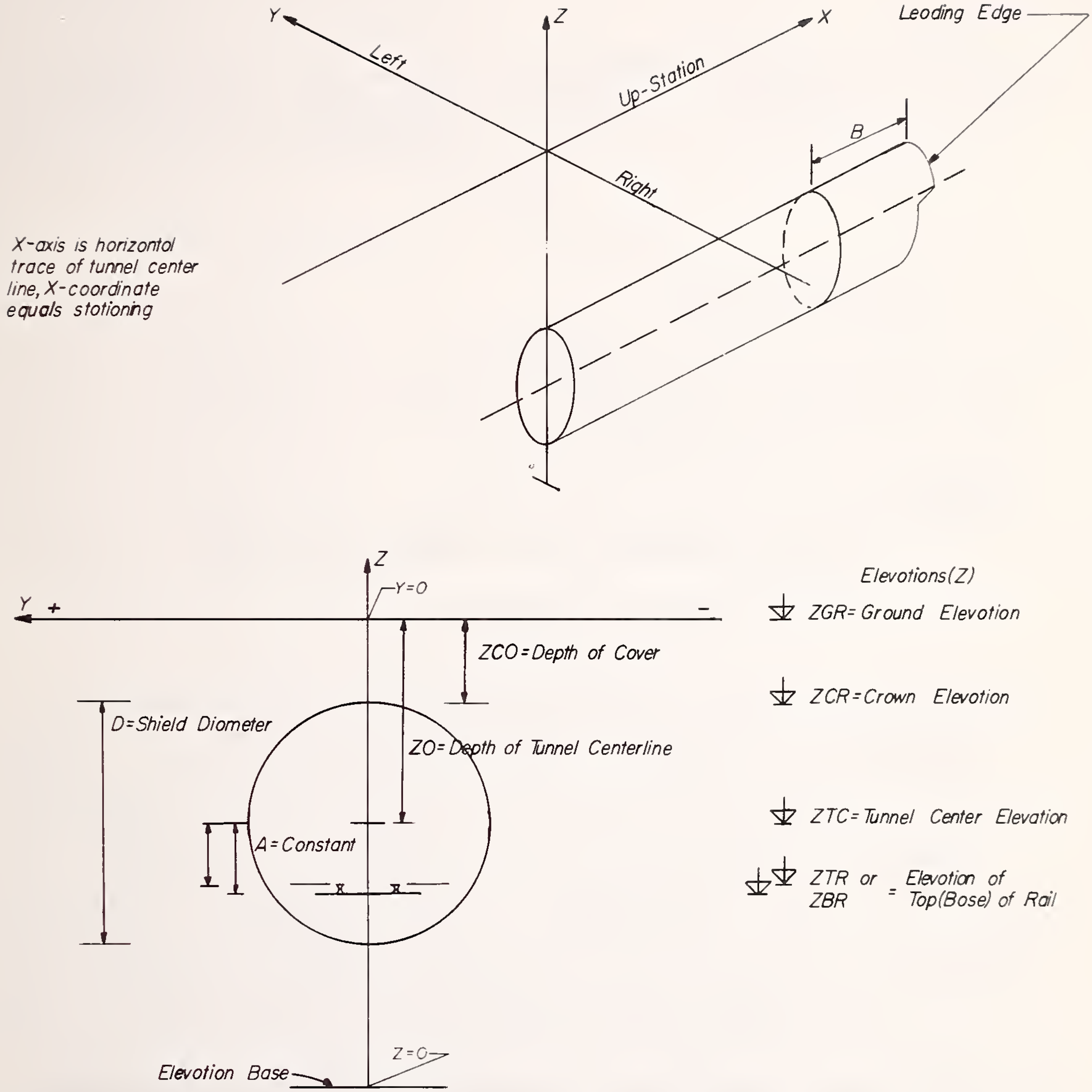
(a) Basic Geometry: Tunnel and shield data may be entered in the following sequence with the command: *TUNN shield diameter (D), length of shield from leading edge to rear of tail (B), height of center over base (top) of rail (A).* (see Fig. F-2). For a given project either base of rail or top of rail are assumed, never both. These data shall be available for analysis.

(b) Vertical Alignment: The definition of the vertical alignment is usually given on construction plans by the stations (x-coordinate) and elevations (z-coordinate) of points of intersecting tangents (profile vertical intersections, PVI), and length of parabolic curves. These data define the vertical alignment completely (see Fig. F-3). These data may be entered by a command *VERT* followed by all PVI data in sequence:

Station, elevation, curve length
station, elevation, curve length

To accommodate the instance where the beginning of a project is on a vertical curve, the user may employ the nearest one or two outside PVI points; hence, for this purpose the computer shall not reject data from outside the project boundaries.

Vertical alignment data will be used for analysis. On retrieval the computer shall be able to compute the base (top) of rail elevation at any identified station, the centerline elevation, the depth of cover and the depth of centerline, using ground surface elevation data from elsewhere, and the



BASIC INPUT: D, A, ZTR or ZBR, B

INITIAL DATA INPUT: ZGR

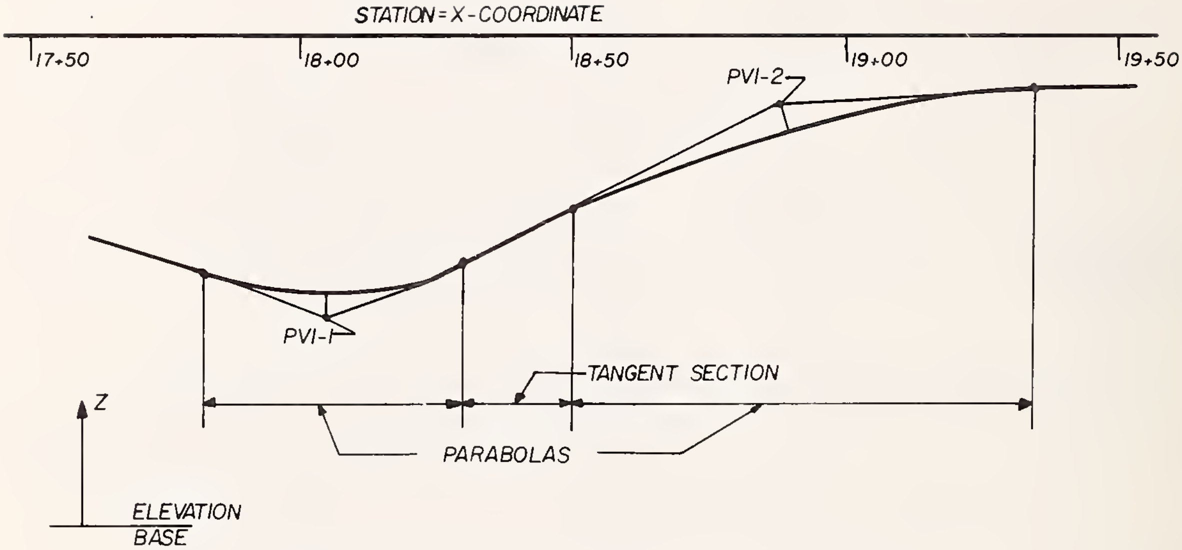
CALCULATIONS: ZCO=ZGR – ZTR + A + D/2

ZO = ZGR – ZTR + A

TUNNEL VOLUME PER FOOT: TVOL=π(D**2)/4

Figure F-2. Basic Coordinate System and Basic Data

VERTICAL:



STATION, ELEVATION OF PVI AND CURVE LENGTH, DEFINE VERTICAL ALIGNMENT

HORIZONTAL:

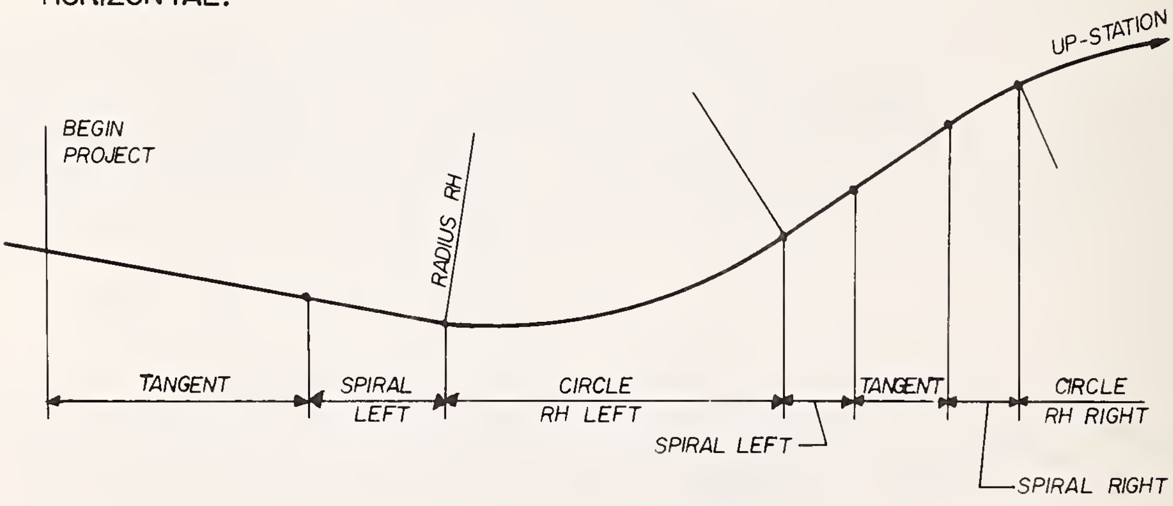


Figure F-3. Basic Alignment Data

instantaneous curve radius.

(c) Horizontal Alignment: Construction plans usually show horizontal alignments incorporating tangent sections, circular curves, and transition spirals. These data will be entered only for the purpose of informational output and not for analysis. A convenient format for input would be:

> *HORI station, argument, station, argument*
> *etc. to the final station.*

where the arguments would be either "tangent," "spiral left or right," "circle radius ___ feet left or right." The first and last station will be used for indicating the beginning and the end of the project or section. On retrieval, these informational arguments will be output (printed) exactly as input for an identified station. If the identified station should hap pen to be exactly one of those indicating boundaries in the original command *HORI*, "tangent" will be output at a tangent/spiral boundary, and "spiral" will be output at a spiral/circle boundary.

6. DATA INPUT - MONITORING DATA

This version of DAPSOG shall consider five different types of monitoring data: surface settlements, deep settlements, horizontal displacements, porewater pressure (i.e. groundwater level), and tunnel progress data. Each of these will have different types and formats of initial data and monitoring data. Initial data are to be input when or before the first monitoring data are input; initial data identify the type, name or number, location and zero point of specific data collection points and cause the opening of a data file of the given name. Monitoring data may be entered later in any order, but identified by data collection point names and dates (and times). In the following, formats are suggested for initial data and monitoring data, for the various data types.

(a) Surface Settlement Points: A name, three-dimensional coordinates, and a time of initiation identify fully a surface settlement point. Initial data may be input by a command: *INIT SS collection point No.*, x_o, y_o, z_o, *date (,time)*, where SS identifies the collection point as a surface settlement data collection point.

Monitoring data consist of new elevations for the same point (measured conventionally in the field by levelling). The identification of the point as a surface settlement (SS) point indicates that changes in coordinate z are to be considered, while x_0 and y_0 are considered constant. Data input will then take the form: *SS collection point No., z_1, date (, time),* where z_1 is the new elevation.

Additional consecutive SS input for different points may be performed for same date (,time) without repeating the date (,time).

Figure F-4 is a sketch showing the geometry of these data inputs, and those of following inputs.

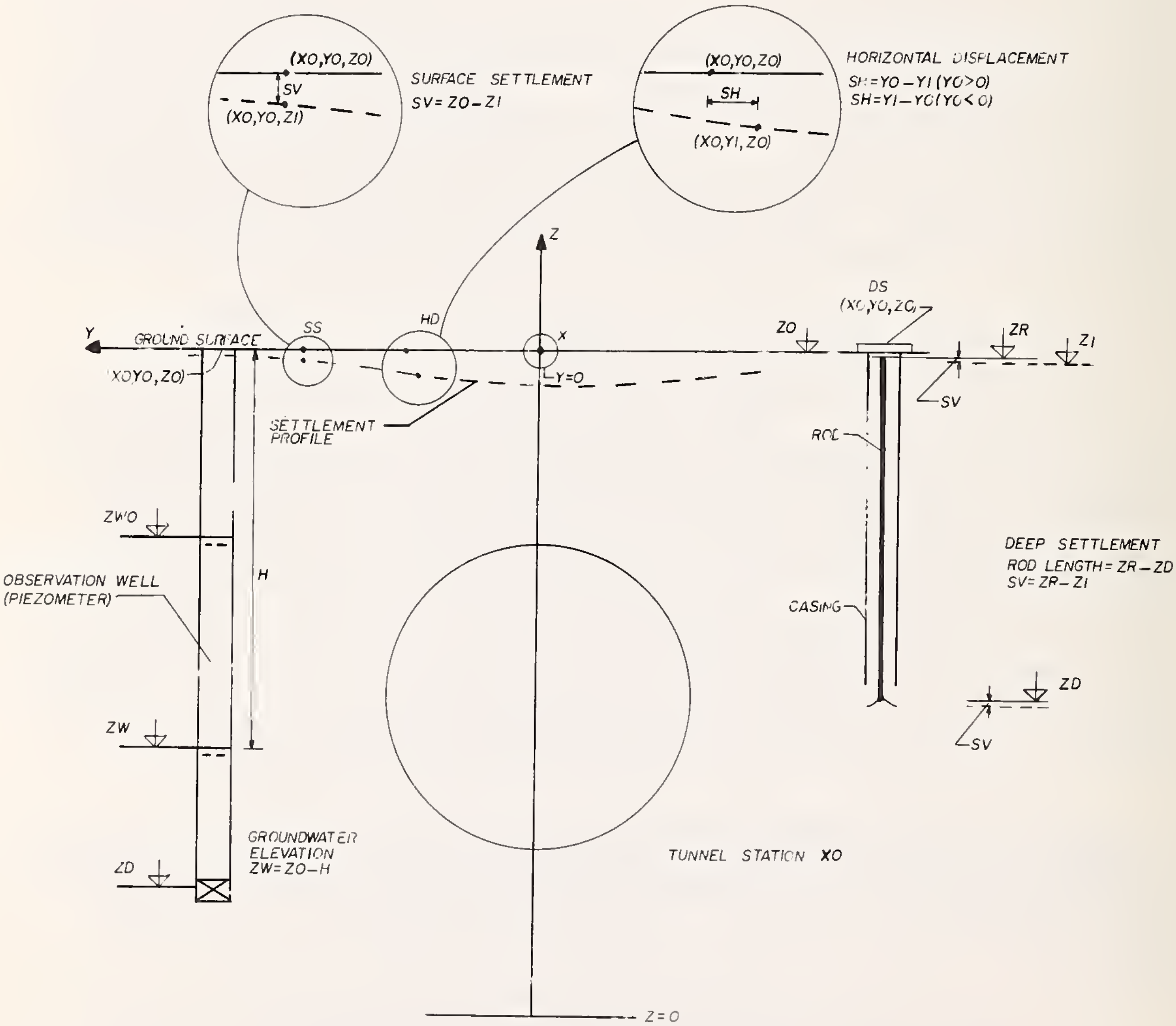


Figure. F-4. General Geometry, Data Collection Points

After input and acceptance, the computer will output a complete listing of the data just input, plus the calculated settlement sv = $z_o - z_1$ in a format as follows:

SURFACE SETTLEMENT point No. XO= , YO= , Z1= , SV=

(b) Deep Settlement Points: Typically, deep settlement points consist of rods fixed at depth and protected by a capped pipe (see Fig. E-4). To identify the initial data completely, two pieces of information in addition to those needed for surface settlement points are needed, the elevation z_d of the point, and the elevation z_r of the top of the rod. The initial data may, then, have this format: *INIT DS collection point No.,* x_o, y_o, z_o, z_r, *date (, time).* The length $z_r - z_d$ is the length of the rod and is presumed to be constant.

Monitoring data from this point consist of new rod elevations z_1, and may be input as *DS collection point No.,* z_1, *date (, time).* The verification output can have the format:

DEEP SETTLEMENT point No. XO= , YO= , ZO= , ZD= , Z1= ,

SV= , date (,time)

(c) Horizontal Displacements: Usually, horizontal displacements will be measured at a number of points along lines at right angles to the tunnel centerline, i.e. with identical x-coordinate. Displacements are referred to a point above the centerline (y = o) presumed not to move horizontally. There are several ways to measure horizontal distances in the field, but in any instance, a single subtraction in the field will refer the distance to the centerline. The required initial data are the same as for surface settlement points, i.e.: *INIT HD collection point No.,* x_o, y_o, z_o, *date (, time).*

In this instance, however, y_o is variable, and monitoring data will be entered as *HD collection point No.,* y_1, *date (, time).*

In the analyses, displacements are considered positive if toward the centerline, i.e. displacement sh = $y_o - y_1$ for $y_o > 0$ and sh = $y_1 - y_o$ for $y_o < 0$. In theory, all displacements should be positive, but in practice negative displacements can occur due to irregularities and inaccuracies of measurement.

Verification output may have this format:

HORIZONTAL DISPLACEMENT point No., XO= , YO= , ZO= ,

Y1= , SH= , date (,time)

(d) Groundwater Data: Observation wells of two types may be used, hydraulic open standpipe, and electrical, identified as PIEZHO and PIEZEL, respectively. Initial data for the open standpipe may be entered as follows: *INIT PIEZHO collection point No., x_o, y_o, z_o, z_d, z_{wo}, date (, time),* where z_d is the elevation of the piezometric tip, and z_{wo} the initial groundwater elevation at the time indicated.

For the open standpipe, monitoring data will consist of new depths to groundwater, h, at given dates. The input format may be *PIEZ point No., h, date (, time).*

For the electrical piezometer, on the other hand, the direct reading must be converted by subtracting it from the zero reading (corresponding to the original groundwater elevation z_{wo}) and multiplying the difference by a calibration constant K. If the zero reading is a_o and the monitoring reading is a, the water height difference would be $\Delta h = (a_o - a)K$, and the new water depth $h = z_o - z_{wo} + \Delta h$. Initial data for the electrical piezometer would then include a_o and K, for example as follows: *INIT PIEZEL collection point No., x_o, y_o, z_o, z_d, z_{wo}, a_o, k, date (, time).* Monitoring data would be input as for the open standpipe, with a input instead of h.

Verification output may have the format:

GROUNDWATER point No., XO= , YO= , ZD= , H= ,

ZW= , date (,time)

(e) Tunnel Process Data: This file should automatically be initiated by the input of basic tunnel data.

The construction progress will be entered at regular brief intervals, on occasions as close as after each shield shove but as a minimum once a day and at the beginning and end of periods of work stoppage. Information may be input relating to progress, f. ex. equipment breakdown, face runs, air pressure, etc. The input format may be *PROG x, date (, time), optional information.* The optional information may be restricted to, say, 30 characters, unrestricted alphameric. The coordinate x is the station or chainage of the leading edge of the shield at the given date and time.

(f) Changing Initial Data: Under certain circumstances, the initial data change and new zero-point data must be supplied. Surface settlement points, e.g., may be removed and replaced by another point at virtually identical x_o and y_o coordinate but slightly different z_o coordinate. Yet, a continuous and consistent record of settlements is required. A rod length may be added or subtracted from a deep settlement point. The ground surface elevation may change at the location of an observation well so that the groundwater depth is measured from a new zero-point. To accommodate these changes, it is proposed that changes in initial data be made possible by simply repeating the initialization command with all items identical to the first initial command, except for the one item changed and the date and time at which the change is effective.

Changes shall not be accepted for parameters other than those specifically allowed: for surface settlement points (SS): z_o; for deep settlement points (DS): z_r; for observation wells (PIEZ): z_o. The changes shall cause all calculations to be based on the new zero data from the indicated data and onward but let data before that date unaffected. A maximum of ten such changes are anticipated for any data collection point.

7. DATA RETRIEVAL - PRINTED OUTPUT

As previously indicated all input data whether basic, initial, monitoring or progress data, shall be output as specified immediately after input and acceptance. Data not accepted shall be output with appropriate error messages.

As a basic principle, all data input and stored in the computer, including names, numbers and initial data as well as monitoring and basic data, shall be available for printed output in annotated format, for the purposes of verification and inventorying. The information needed may be listings of observation points in a given coordinate range, listings of initial data, or listings of monitoring data in selected ranges. Three types of commands are suggested, a *DIREC* tory command for inventory purposes, a *BASIC* command for output of basic or initial data, and a *PRINT* command for output of monitoring data, each followed by two arguments, arg_1 and arg_2 indicating the type and range of the desired output.

The following options are suggested:

DIREC ALL: Will print job name, initial date, all instrument names (Nos.) with indication of type, coordinates, and initialization data, with dates.

DIREC Instrument type (e.g. SS) : Will print all instrument names (Nos.), with coordinates and all initializing data, with dates, of instrument type indicated.

DIREC Instrument name (No.): Will print type, name, coordinates and all initializing data for named instrument.

The first two of these commands may be followed by a second argument, separated by a comma, indicating stationing (see page F-7).

BASIC ALL: Will print all data on tunnel geometry stored on this project.

BASIC Station (x-coordinate): Will print top/base of rail at named station, tunnel center elevation, crown elevation, and nearest ground surface elevation (z_o-coordinate), as well as local horizontal and vertical curve information. Will also print date (,time) tunneling passed this station (if available).

BASIC FROM STAT____TO ____: Will print all geometric data in the indicated interval and all available ground surface elevations in this interval along the centerline or for $|y_o| < 4$ feet (see page F-7).

The *PRINT* command is followed by three arguments arg_1, arg_2, arg_3.

arg_1 indicates instrument type (SS, DS, HD, PIEZ).

arg_2 indicates instrument name (No.). Several instrument names may be entered here, limited only by space on one card.

arg_2 alternatively can be a station argument (see page F-7), indicating that data from all instruments of named type in indicated x-coordinate range are desired.

arg_3 is the time argument; three alternatives, 1) a simple date (,time) indication will print the first data available after this date, 2) time argument alternatives as on page F-6 may be used, 3) arg_3 = blank prints all available information.

To print progress information, there will be only two arguments after *PRINT: PROG* indicates that progress information is desired, and the second argument is the time argument as previously treated.

8. DATA RETRIEVAL - PLOTTED OUTPUT

This version of DAPSOG shall consider output plotted by line printer or plotter at the user's option. For increased accuracy in line printer output, points shall be plotted using a nine-letter convention as shown on Fig. F-5.

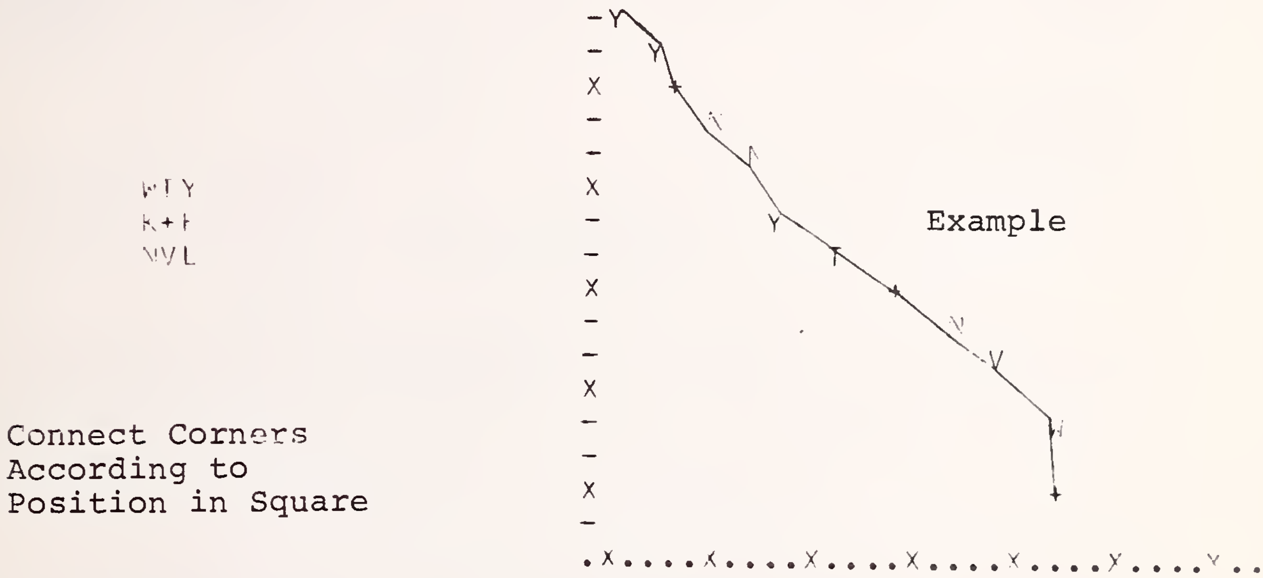


Fig. F-5: Nine-Letter Plotting Convention

A variety of plots may be selected by the user; sketches of these plots are shown on Figs. F-6 through F-12. The plots may be of data from a single instrument or data collection point versus time or from a number of points versus x or y coordinates. The results of certain defined analyses will be printed after plotting.

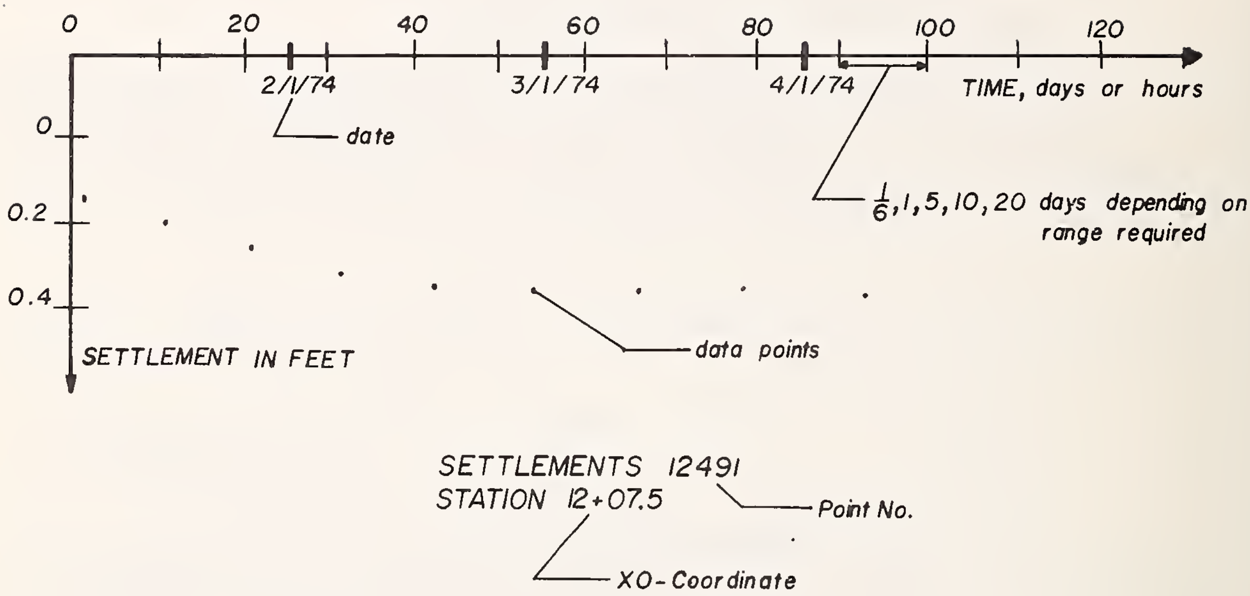
A plotting command must therefore include most of the following arguments following a *PLOT* command:

(a) Type equipment (line printer or incremental drum plotter)

(b) Type of plot (numbered option)

(c) Instrument type)
) if single instrument data output
(d) Instrument name)

Settlement Data (Surface or Deep) Versus Time



Single Horizontal Displacement Versus Time

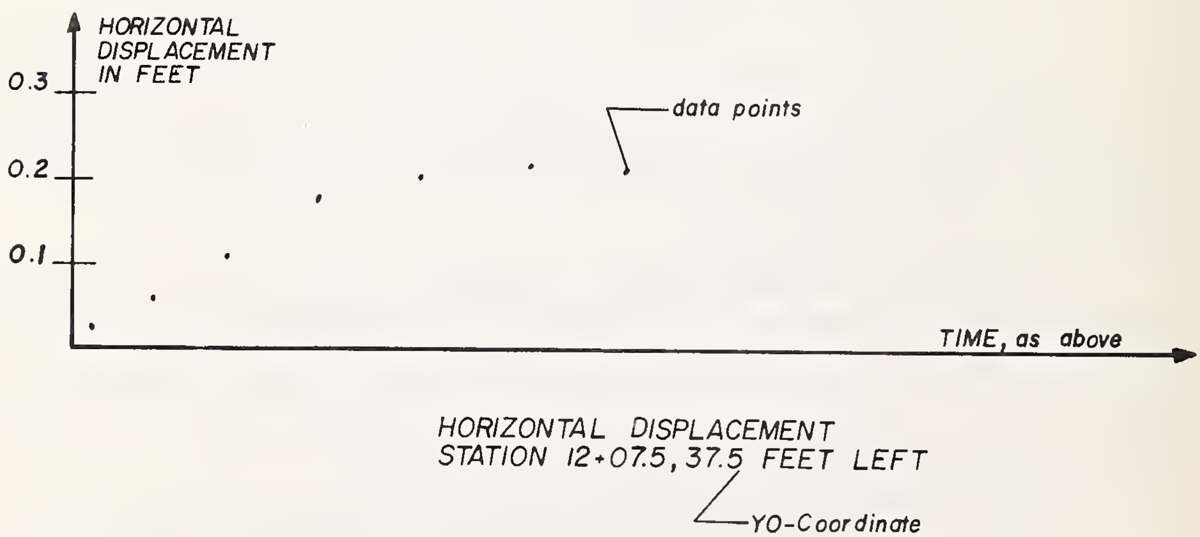


Figure F-6. Plot Type 1

(e) Station or range of stations

(f) Time or range of time

(g) Analysis option

In general, time scales are to be selected automatically to fit available space, with the following standard options for time divisions on the plot: One division = 4 hours (1/6 of a day); 1 day; 5 days; 10 days; 20 days. Dates shall be written on the time scale to fully identify the time scale. Time axes are to be horizontal.

Scales of length (x, y, z - coordinates) shall also be selected automatically to fit available space, with the following options: One division = 5 feet; 10 feet; 20 feet; 50 feet; 100 feet; 200 feet; 500 feet. These scales also apply to output of groundwater elevation data.

Scales of displacements (settlements, horizontal displacements) shall be selected automatically to fit available space as well, with options: One division = 0.05 feet; 0.1 feet, 0.2 feet and 0.5 feet. Displacement axes are vertical. In general, the plots are desired to be about three times as wide horizontally as vertically.

Plot Type 1: On a horizontal time scale, settlement or displacement data from a single point are plotted on vertical scales (Fig. F-6). Settlements sv are plotted positive downward, but horizontal displacements sh are plotted positive upward. The required command must include type equipment, type plot (1), instrument type (SS, DS, HD), instrument name or number, time or time range. If the time argument is left blank, all available data are plotted; if a single time is given, all data after this time is output; or desired time range may be given by *FROM date (, time) TO date (, time)* or any other option as shown on page F-6. The plot title will be SETTLEMENTS, HORIZONTAL DISPLACEMENTS, or DEEP SETTLEMENTS, followed by point No., and STATION (x_o-coordinate), $|y_o|$ FEET LEFT or RIGHT (if y = 0), and POINT ELEVATION z_o (if deep settlement point).

Plot Type 2: Tunnel Progress Data plotted against time (Fig. E-7). This plot frequently follows immediately after a plot of type 1 and should use an identical type of time scale. The *PLOT* command would contain the following information: Type equipment, type plot (2), time argument (as for plot type 1). If on line printer, optionally input alphameric progress

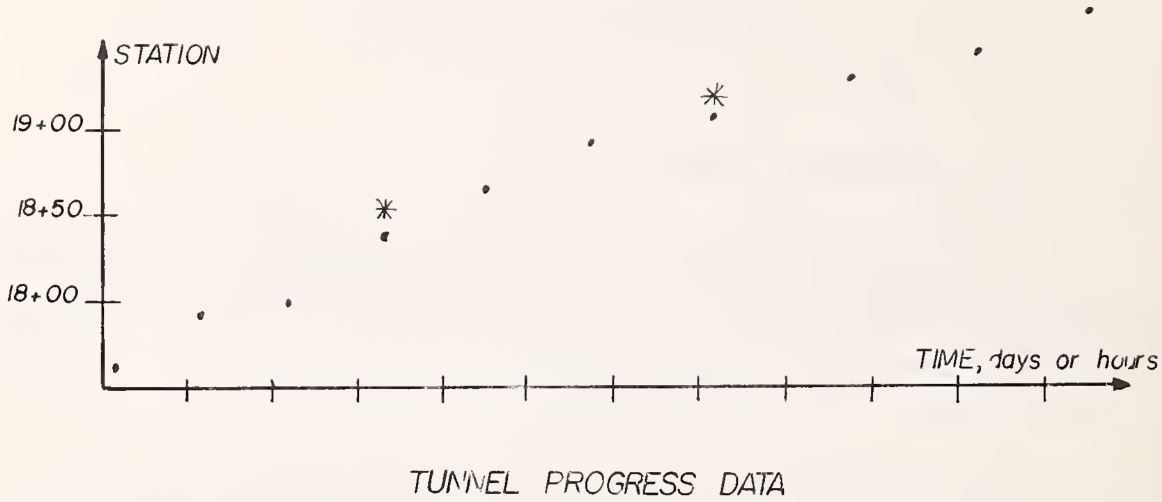


Figure F-7. Plot Type 2

commentary will be printed on the lines following the plot. On plotter, asterisks will indicate where such alphameric commentary is available, and the data will be printed automatically on the line printer following the plot.

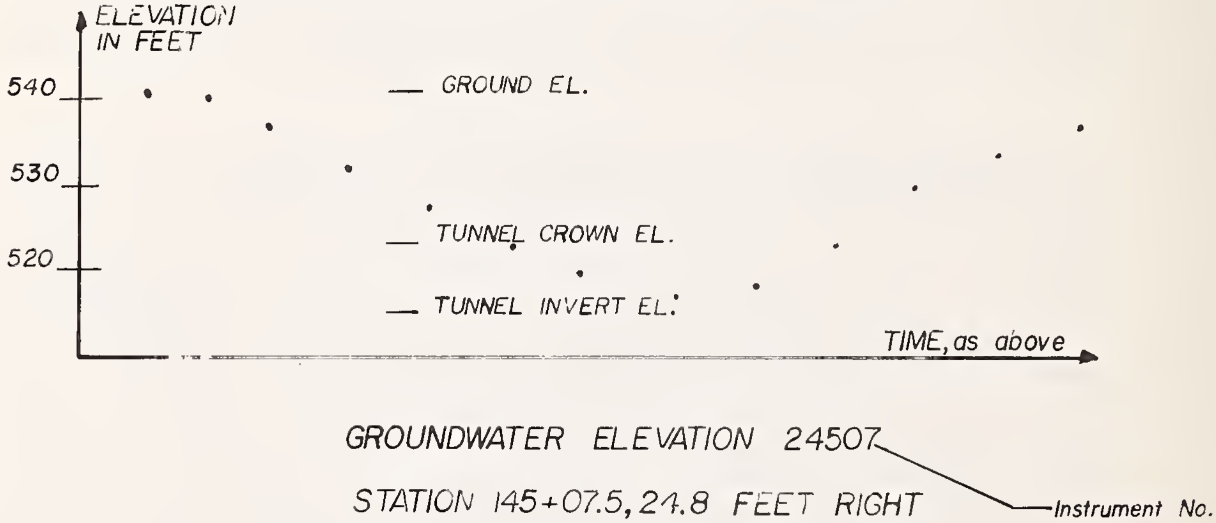


Figure F-8. Plot Type 3

<u>Plot Type 3:</u> Groundwater Elevations Versus Time, plotted vertically above the usual time axis. *PLOT* command includes type equipment, type plot (3), point no., time argument (as above). The plot shall include indications of ground elevation, tunnel crown elevation and invert elevation as shown on Fig. F-8.

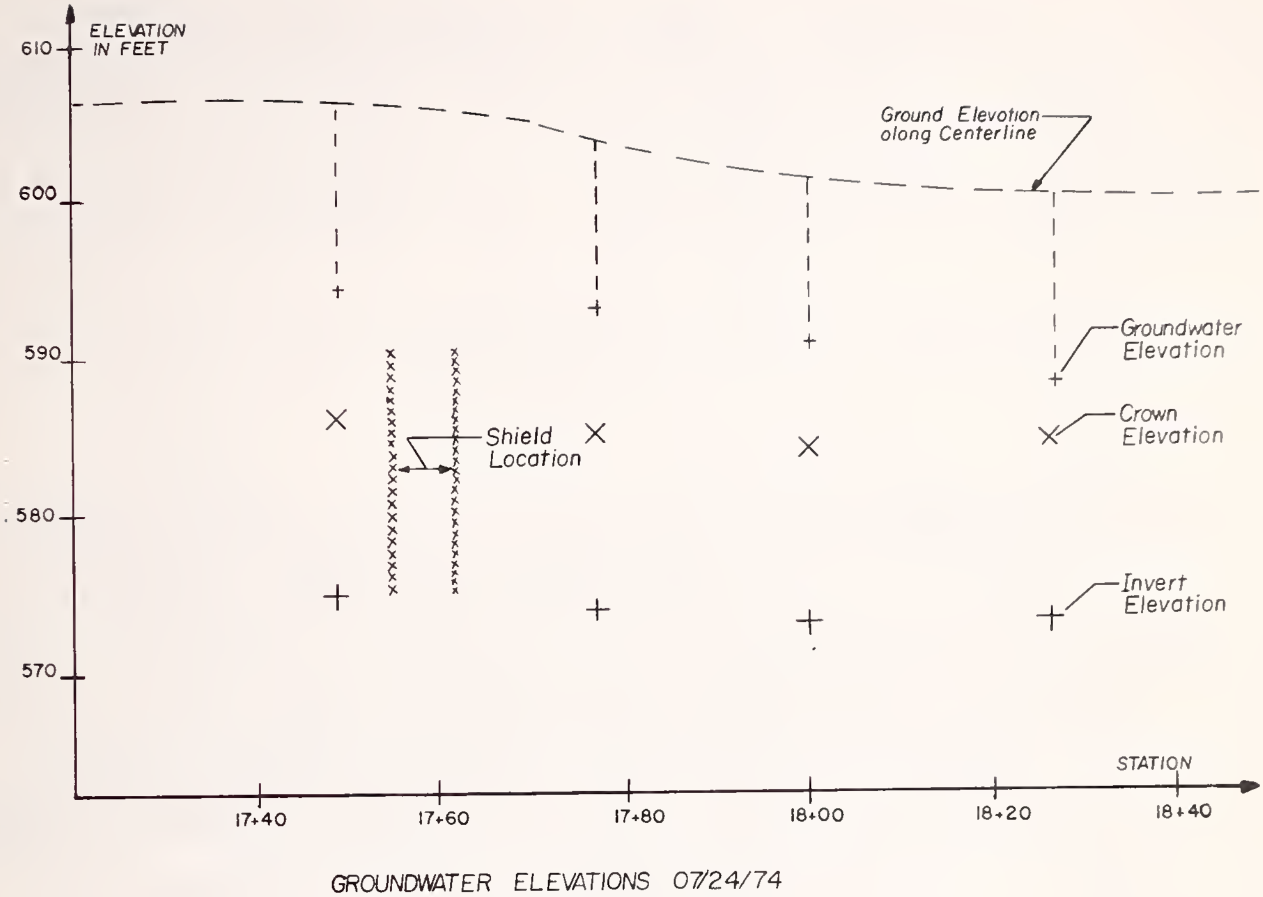


Figure F-9. Plot Type 4

Plot Type 4: Longitudinal Geometry and Groundwater, shows elevations of ground surface along centerline ($|y| \leq 5$ feet), elevations of tunnel crown and invert at selected points, and groundwater elevations from all observation wells within given stations (x-coordinate); last reading before a given date (,time) (see Fig. F-9). Required *PLOT* command: type equipment, type plot (4), station range (see page F-6), time. Also shows location of shield at this time.

Plot Type 5: Settlement Data (Surface or Deep) Along Centerline ($|y_o| \leq 4$ feet), at given date; shows also location of shield (see Fig. F-10). Required *PLOT* command includes: type equipment, type plot (5), type instrument (SS or DS), station range, date. Analysis of these data, see later.

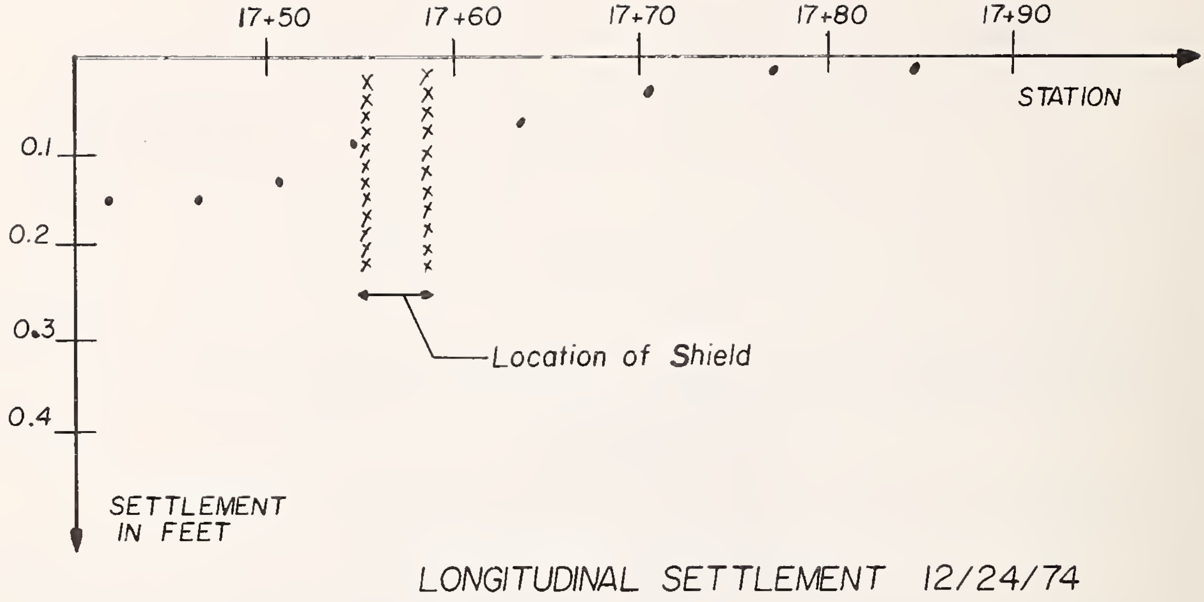


Figure F-10. Plot Type 5

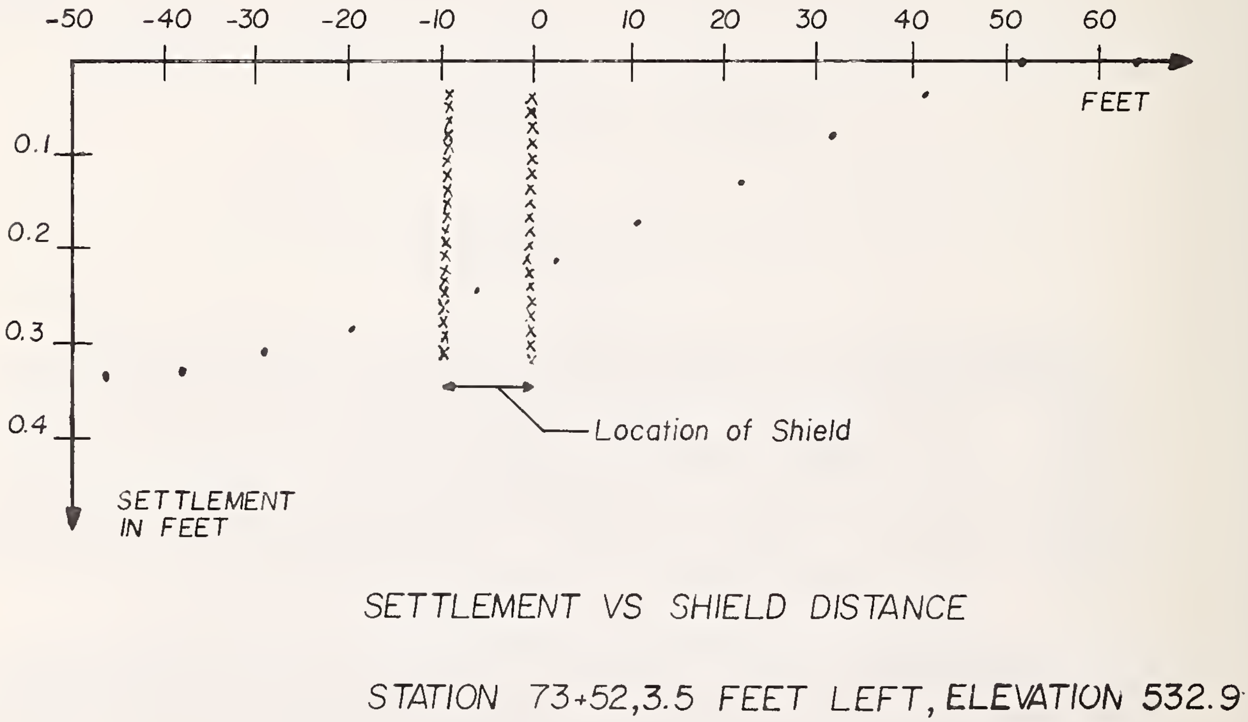


Figure F-11. Plot Type 6

Plot Type 6: Settlement Data (Surface or Deep) ($|y_o| \leq$ 4 feet) as function of distance from shield leading edge, shows data from a given point (Fig. F-11). The horizontal axis coordinate is found by subtracting the x-coordinate of the shield at the time of a reading from the x_o-coordinate of the data collection point. The horizontal axis shall extend approximately as far in each direction as two and a half times the depth of the tunnel centerline (z_o).

The required *PLOT* command will include: equipment type, type plot (6), type instrument (SS or DS), instrument No.

For analysis of these data, see page F-25.

Plot Type 7: Cross Section Plot, will plot all surface settlement and horizontal displacement data at a given station and date, as functions of distance from the centerline (y_o-coordinate). The x_o-coordinate of points desired for this plot may not be exactly the same for all of them; hence, the PLOT command will require only an approximate x_o-coordinate and all data within a range of $x_o \pm$ 5 feet will be plotted. As shown on Fig. E-12, settlements are positive downwards and horizontal displacements are plotted positive upwards. The required *PLOT* command will include: equipment type, type plot (7), station, date.

For analysis of these data, see page F-25.

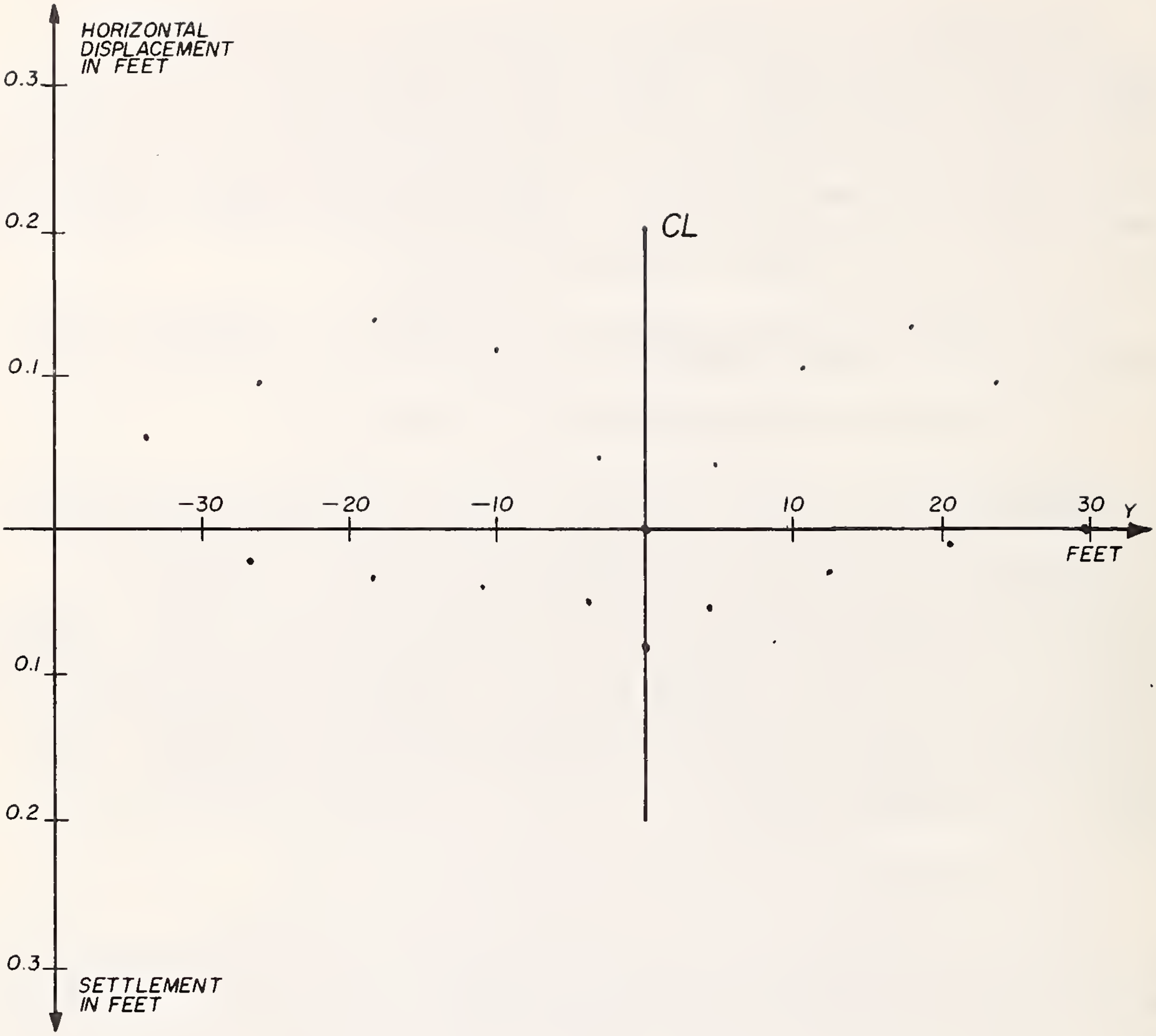
Note: For all of these plots, provisions must be made for output of error messages whenever nonexisting data are requested. Wherever a print, plot or analysis requires the position of a shield at a time where the shield position is not exactly identified by entry at that time, straight-line interpolation between two nearest time entries shall be employed, assuming constant rate of production.

9. INTERPRETIVE ANALYSES - PRINTED OUTPUT

Certain interpretive analyses will be executed on the data output in plots of types 5, 6, and 7. These analyses shall be performed and the results printed when a code is added at the end of the appropriate *PLOT* command.

Analyses for 5 and 6: The data may be approximated by a Gaussian cumulative distribution function, equation

$$sv = svmax \int_{-\infty}^{x} \frac{1}{i\sqrt{2\pi}} \exp\left(-\frac{x^2}{2i^2}\right) dx.$$



CROSS SECTION DATA

STATION 27+15.2, 12/17/74

SHIELD LEADING EDGE AT 27+17.4

(On line printer : G

ELEVATIONS: TOR=742.27, CL=745.37, CROWN=753.27
GROUND=777.33, GROUNDWATER=741.96

CURVES: VERTICAL=TANGENT -3% DOWN
HORIZONTAL = 2070 FEET LEFT)

Figure F-12. Plot Type 7

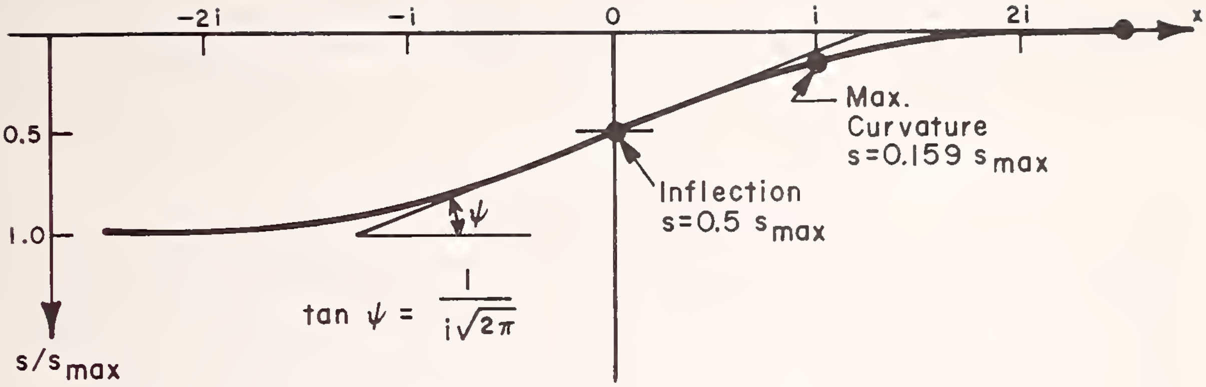


Figure F-13. Subsidence Along Centerline Approximated by Gaussian Cumulative Distribution Function.

In this equation, sv represents the measured settlement data as a function of x, svmax is approximately equal to the maximum settlement measured (provided the shield has passed sufficiently far so that settlements are virtually complete), and i is a horizontal distance (see Fig. F-13). There are three unknowns to determine by curve fitting: the best fitting value of svmax, of i, and the best fitting location of the point of inflection, at x-coordinate xa. The point of inflection is the point where, in theory, the slope of the settlement profile is greatest and where the settlement is equal to ½ svmax; it is usually located close to the x-coordinate of the leading edge of the shield.

The contractor shall determine the most suitable method of curve fitting for this purpose and shall write the necessary program. If insufficient data are available for making a meaningful analysis, an output message shall so state. If the analysis can be made, the printed output shall consist of the following items:

```
SVMAX=    FEET; I=    FEET, XA=    FEET
POINT OF INFLECTION TRAILS (LEADS) LEADING
EDGE OF SHIELD BY     FEET,
QUALITY OF CURVE FITTING:  (EXCELLENT, GOOD, FAIR, POOR)
```

where the trails (leads) item is the difference between xa and the x-coordinate of the shield edge.

<u>Analysis for 7</u>: The cross section surface settlement profile may be approximated by the subsidence function (similar

to the error function, see Fig. F-14)

$$sv = svmax \exp \left(- \frac{(y-ya)^2}{2i^2}\right).$$

where svmax is the theoretical maximum settlement, and i the trough width parameter. In theory, svmax occurs for y=ya=0 and the function is symmetrical about y=ya. There are three unknowns in this analysis: the theoretical value of svmax, of i, and the actual value of ya, the point of symmetry, if different from zero. When sufficient data are available, all three unknowns may be found through curve fitting. When insufficient data are available, the analysis may be restricted by fixing the point of symmetry as y=ya=0. Note that the function is transformed into a linear relation between log sv and y^2 (or $(y-ya)^2$) by taking the logarithm:

$$\log sv = \log svmax - \frac{(y-ya)^2}{2i^2} \log e.$$

Once the values of svmax and i are found, the cross section area of the settlement trough (the settlement volume per foot VS) may be found as VS = 2.5 i svmax. The percent ground loss is found as the percentage ratio of the settlement volume per foot to the cross section area of the tunnel shield, $\frac{\pi D^2}{4}$.

The output from this analysis in printed form shall consist of:

```
SVMAX        FEET; I=     FEET; YA=     FEET
SETTLEMENT IS SKEW (ya) FEET RIGHT (LEFT)
QUALITY OF FIT
SETTLEMENT VOLUME SV=     FEET **2/FOOT
ESTIMATED GROUND LOSS=       PERCENT
DIMENSIONLESS DEPTH PARAMETER ZØ/D=
DIMENSIONLESS TROUGH WIDTH PARAMETER 2I/D=
THEORETICAL TROUGH WIDTH PARAMETER (ZØ/D)**0.8=
MAXIMUM HORIZONTAL DISPLACEMENT SHMAX=   FEET AT Y=    FEET
SHMAX/SVMAX=
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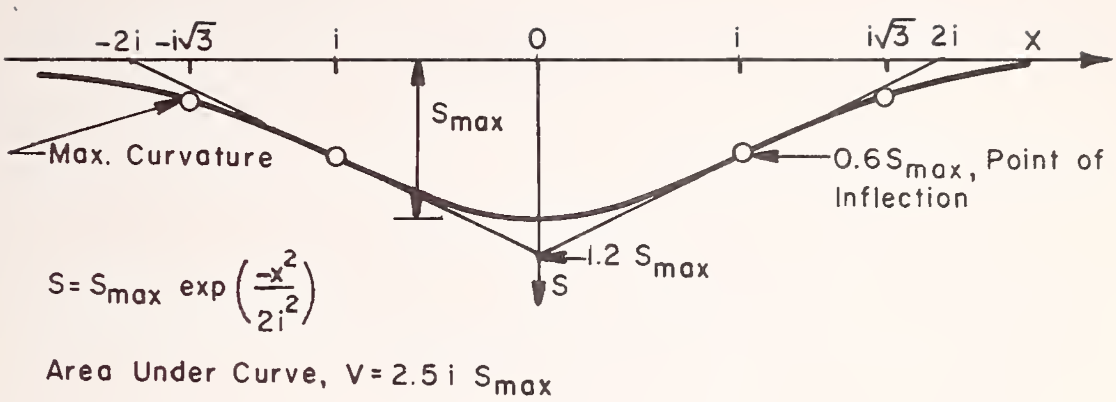

Figure F-14. Error Function used to Describe the Settlement Trough.

APPENDIX G

TECHNICAL SPECIFICATION
FOR MANUFACTURE, INSTALLATION
AND TESTING OF
COMBINED EXTENSOMETER/PIEZOMETER

CONTENTS

NOTE: Appendix A is to be used for quality control inspection of any instrument prepared in accordance with this appendix.

1. INTRODUCTION

Measurements of groundwater level or piezometric head are used for control of dewatering efficiency and for assessment of tunnel and excavation stability and safety. Piezometers installed just above the tunnel crown provide a means of monitoring the groundwater regime above and ahead of the tunnel and as such are valuable predictive and diagnostic tools.

Measurements of settlement just above the tunnel crown permit an evaluation of the source of lost ground and hence provide data for the planning of remedial measures. Such measurements also permit a prediction of settlement at other similar locations. These measurements are made using a single point embedded extensometer. By monitoring settlement must above the crown rather than at the ground surface information is gained much sooner, and the specific cause of lost ground is not masked by strains within the soil above the tunnel. Remedial action can therefore be taken more quickly and effectively, at minimum cost.

Current practice entails only occasional effort to monitor these two parameters, and a separate boring is required for each instrument. The merits of making the measurements are insufficiently recognized, and the cost of doing so is a discouragement. This specification outlines the requirements for a combined extensometer/piezometer for installation in a single boring.

2. CONTRACT OBJECTIVES

The objective is to design, manufacture, field test and prepare detailed specifications for commercial manufacture and usage of two models of extensometer/piezometer. One model is to be used where unhindered access to a surface point directly above the instrument is possible, and the other model is to be used where such access is not possible. Primary considerations in meeting this objective are simplicity, economy of hardware and installation, and reliability.

This contract includes the following tasks:

1. Design and fabricate three each of the two models.

2. Conduct laboratory tests on electrical components.

3. Conduct field installation trials using all six instruments in an environment where settlement and pore pressure are changing.

4. Revise designs and/or installation procedures in accordance with results of field trials.

5. Develop production drawings and specifications for the hardware.

6. Prepare a manual describing theory of operation, installation procedures, reading procedures, data calculation and presentation procedures, and maintenance procedures.

7. Prepare guidelines for appropriate usage of the instrument on tunnel projects, including estimated hardware, installation, and data acquision costs.

Preliminary conceptual design and performance criteria are specified in Sections 3 and 4 of this appendix. The development shall not be limited to the concepts described in this appendix. Alternate types of systems may be considered as long as they fulfill the basic requirements stated in these specifications, including the requirements of simplicity, reliability and economy. Significant deviations from the preliminary conceptual design shall be subject to approval by the technical monitor.

3. CONCEPTUAL DESIGN OF INSTRUMENT

3.1 Accessible Instrument

An accessible instrument is one which is intended for use where continued access to the top of the installation boring is feasible and safe.

The piezometer shall consist of an open standpipe piezometer packaged with an anchor post or mechanical rod extensometer.

3.2 Inaccessible Instrument

An inaccessible instrument is one which is intended for use where access to the top of the boring is not feasible, either for safety or construction reasons.

The piezometer shall consist of a diaphragm type electrical pressure transducer packaged with a rod extensometer using an electrical linear displacement transducer. Electrical cables will be laid to an appropriate remote accessible readout location.

3.3 Seal Between Piezometer and Soil

The objective of piezometric measurements is to monitor the groundwater regime above and ahead of the tunnel in soils with a permeability down to 1×10^{-5} cm/sec. The primary interest is the elevation of the water table in a relatively permeable soil, at the tunnel crown rather than in piezometric head of a clay subjected to consolidation. The appropriate water table may or may not be perched. It will generally not be necessary to seal the piezometer within a small zone of soil as would be required for monitoring the consolidation process. Conceptual designs are suggested herein which, if soil conditions permit, enable the piezometer to be pushed into place below the bottom of a boring. This procedure in itself should provide an adequate seal for the stated purpose. Since the instrument would usually be used in soils with little or no clay, the effect of smear on the piezometer efficiency may be presumed to be small. In soils that do not permit pushing the instrument into place, separate measures shall be taken to create appropriate seals so that the piezometer responds to the water table existing at that point. These measures shall exclude surface water and water from any overlying perched water tables. In these cases it may be necessary to adopt conventional piezometer sealing procedures using bentonite or grout.

4. CRITERIA FOR HARDWARE AND INSTALLATION PROCEDURES

The instruments shall conform to the following criteria:

4.1 General Criteria

1. The instruments shall conform with the requirements of Appendix A "Interim Quality Control Specification for Procurement of Geotechnical Instrumentation for Use During Construction Monitoring of Soft Ground Rapid Transit Tunnels."

2. Instruments shall consist of a single "accessible" model and a single "inaccessible" model, applicable to all soft ground subsurface conditions and to all anticipated ranges of settlements and pore pressure changes as defined in paragraph 4.2 below.

3. The hardware development and field test effort shall be completed within a 24-month period.

4. Hardware, data handling and installation procedures shall be selected to create compatibility between the two separate components. For example, the piezometer and extensometer should not require two different sets of data acquisition hardware unless those items are both simple and inexpensive.

5. The maximum outside diameter of any part of the system which is to be installed in a borehole shall permit installation through a 2-3/8 inch inside diameter boring casing.

4.2 System Range and Precision

The instruments shall permit measurement of settlement to a precision of ±0.01 feet with a range of 18 inches, and piezometric head to a precision of ±0.3 feet of water with a range of zero to 200 feet of water.

4.3 Extensometer for Accessible Instrument

1. The extensometer for the accessible instrument shall be either an anchor post or rod extensometer. These devices permit a measurement of the change in distance between the anchor (just above the tunnel crown) and the reading head (at the ground surface), and are illustrated schematically in Figs. G-1 and G-2. If the anchor is settling, the ground surface may also be settling, and therefore this measurement alone cannot be used to determine settlement. Absolute settlement is determined by reference to a benchmark using conventional optical survey techniques.

2. The anchor may be hydraulic or mechanical. If hydraulic, provision must be made to determine, by monitoring hydraulic oil volume, the extent of actuation. The anchors shall actuate at a hydraulic pressure not greater than 800 psi and the anchor chamber and oil line shall sustain an oil pressure of 2,500 psi.

3. Various short length of rods shall be provided so that the top may be terminated at an appropriate level with respect to the ground surface.

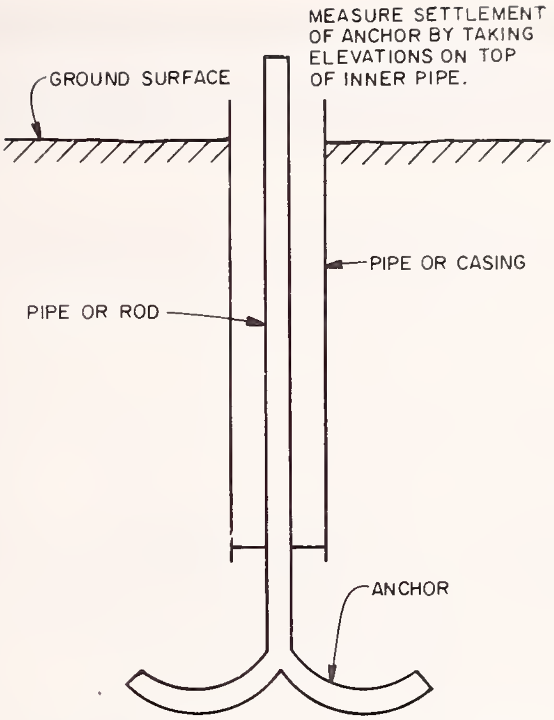

Figure G-1. Anchor Post

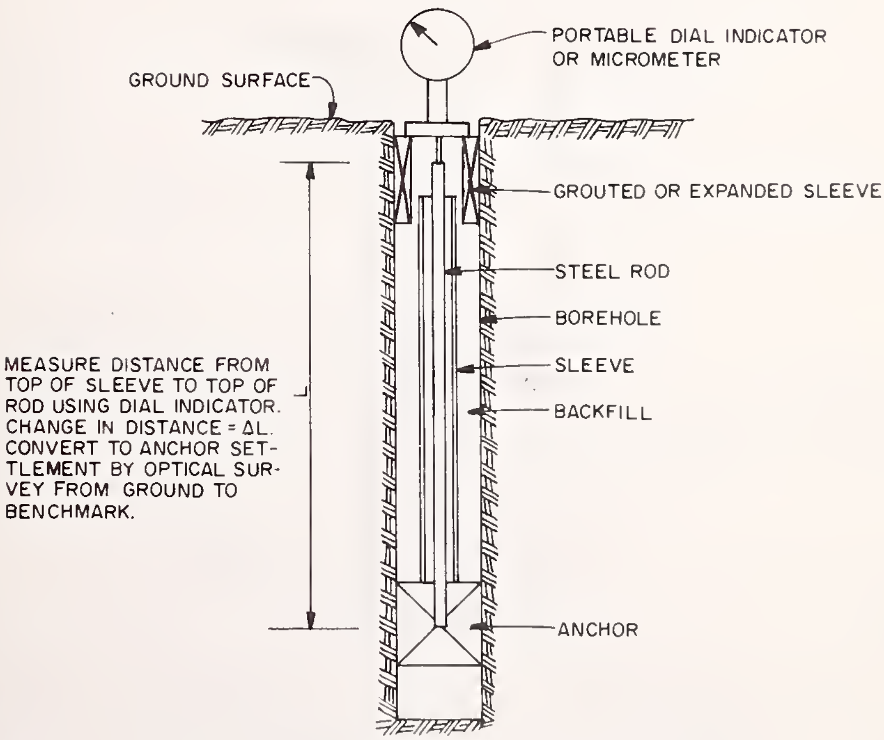

Figure G-2. Rod Extensometer with Mechanical Readout

4.4 Piezometer for Accessible Instrument

1. The piezometer for the accessible instrument shall be an open standpipe piezometer. A schematic of the measuring principle is shown in Fig. G-3.

2. The outside diameter of the porous filter shall not be less than 1-1/4 inches and the length not less than 8 inches.

3. The porous filter shall have a pore size of approximately 2 microns.

4. The inside diameter of the standpipe shall not be greater than 0.2 inch.

5. The method of reading depth to water surface in the standpipe shall be one of those listed in (a) through (d) below, or equivalent method. This measurement will be converted to an elevation by measuring the elevation of the ground surface using conventional optical survey techniques.

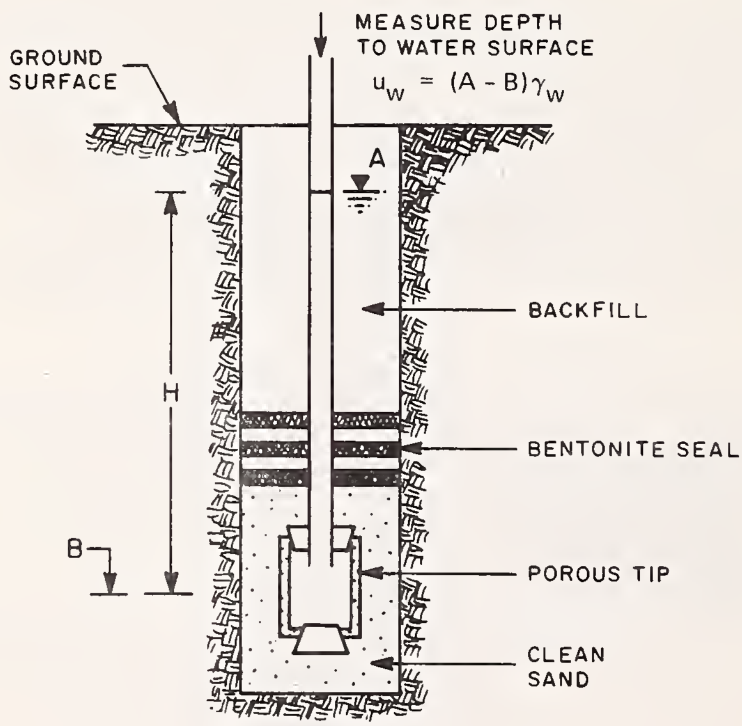

Figure G-3. Standpipe Piezometer

(a) A graduated coaxial or twin conductor electrical cable connected to a battery and galvanometer. When the bared cable end contacts the water surface an electrical circuit is completed, as indicated by the galvanometer.

(b) A thermistor (sensitive temperature sensor) housed in a probe, connected to a graduated electrical cable and indicator unit containing battery and ohmmeter. When the thermistor contacts the water surface, the ohmmeter indicates a temperature change.

(c) A graduated fine nylon tube, with lower end open and upper end connected to a housing containing a sensitive pressure transducer. When the lower end of the nylon tube is submerged below the standpipe water surface, a positive pressure is created in the tube and actuates the transducer indicating meter.

(d) A "capillary reader". The device consists of a graduated fine nylon tube, with lower end open and upper end submerged below the surface of colored water contained in a test tube. Prior to submergence of the lower end below the standpipe water surface, the colored liquid within the upper end of the tube is held above the test tube water level by capillarity. On submergence, the capillary rise is depressed by air pressure in the tube. Observation of the capillary level indicates when standpipe water is encountered. Tools for making this type of measurement are generally available and should not be considered objects of development within the contract unless so approved by the technical monitor.

4.5 Packaging of Accessible Instrument

1. Conceptual sketches of two possible packaging arrangements are shown in Figs. G-4 and G-5. One arrangement only shall be selected for manufacture, installation and testing. The following shall be evaluated prior to selecting final packaging arrangements:

(a) Position of piezometer filter with respect to extensometer anchor. Either one may be below the other.

(b) Type of borehole linkage. Borehole linkages are discussed further in Sections 4 and 5 below.

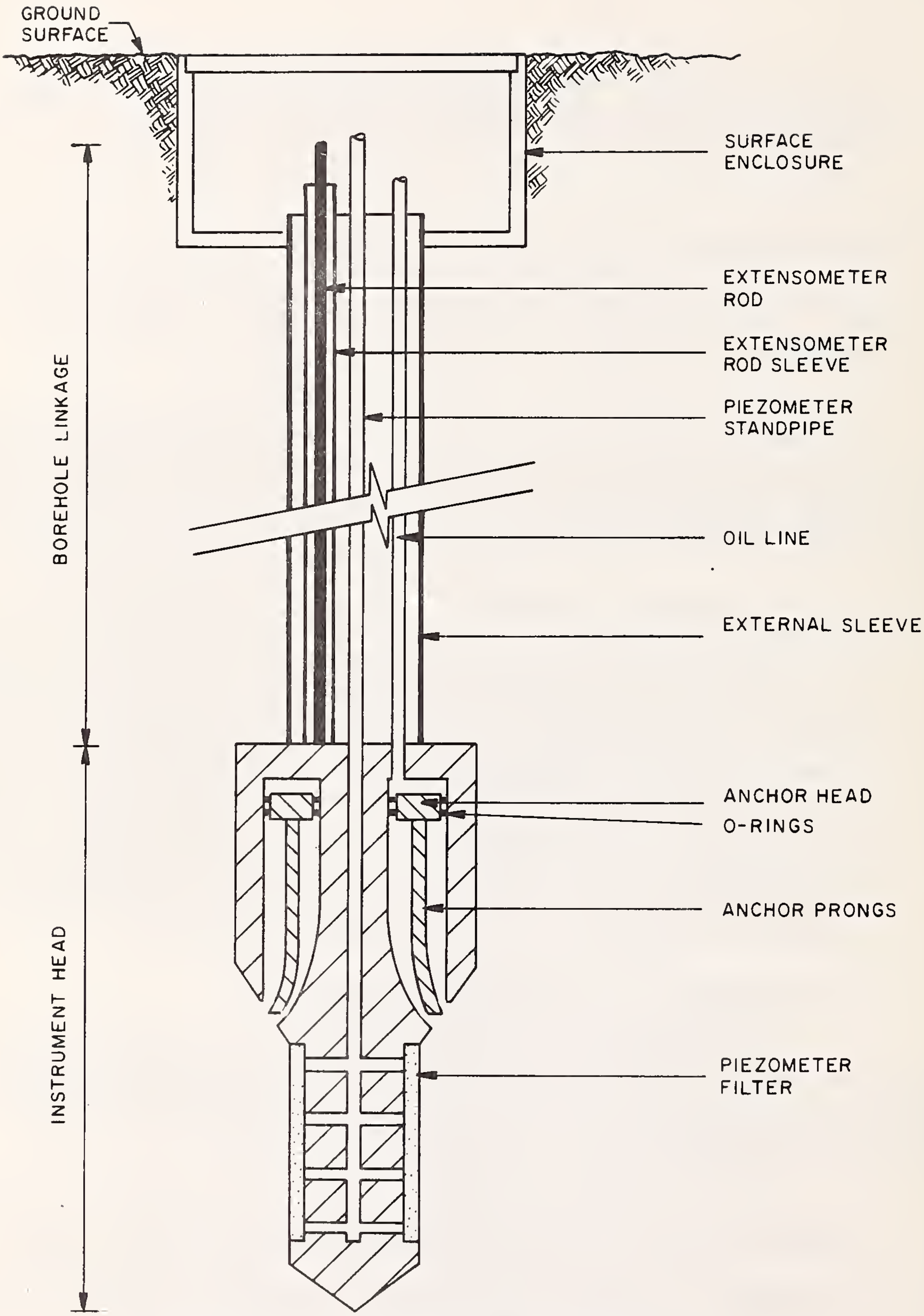

Figure G-4. Conceptual Sketch of Accessible Instrument Arrangement 'A'

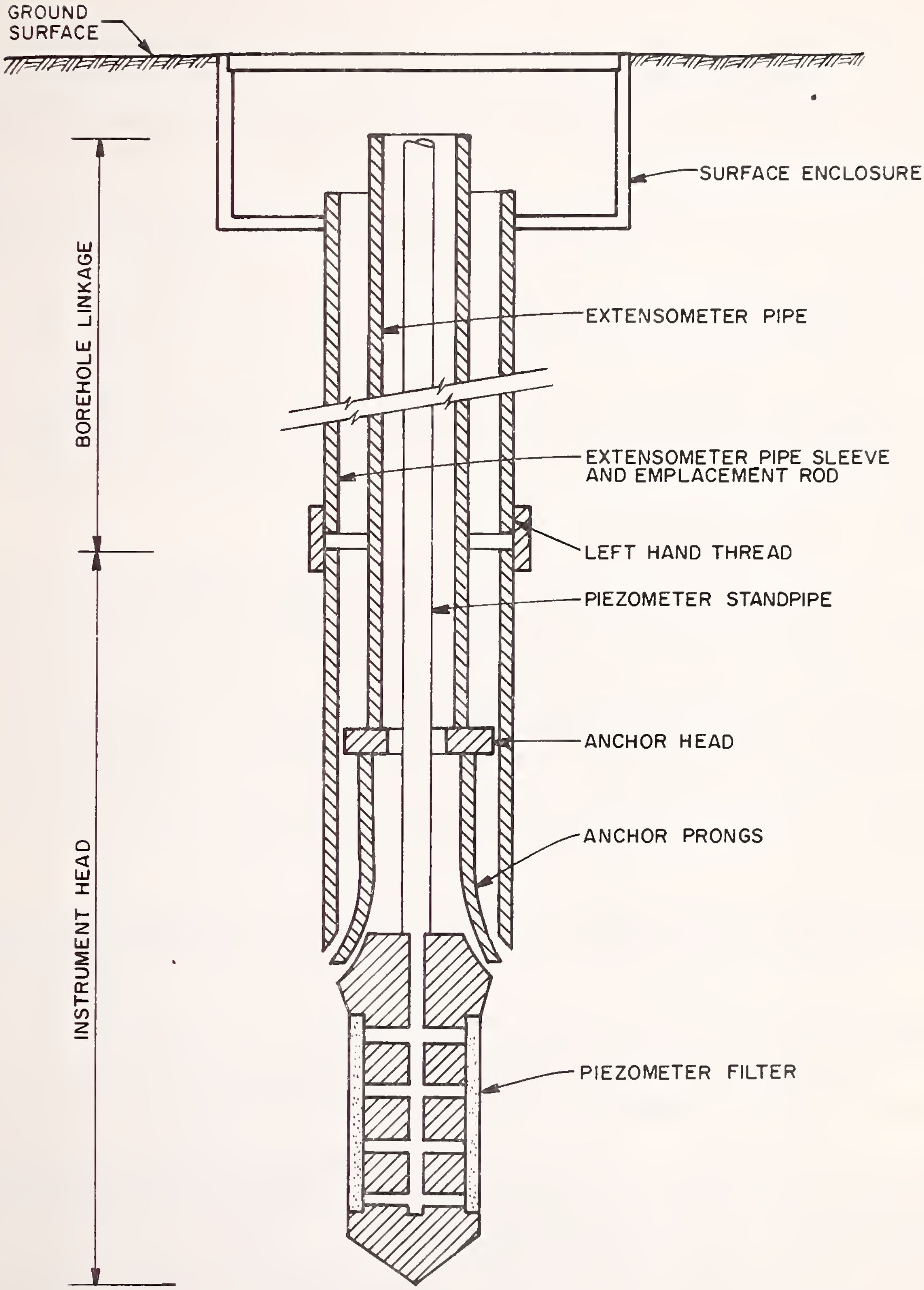

Figure G-5. Conceptual Sketch of
Accessible Instrument Arrangement 'B'

2. Packaging shall be consistent with acceptable installation methods, as discussed in paragraph 4.9. Special attention shall be made to minimize necessary field installation skill and time.

3. On occasion it may be necessary to seal the instrument in place using conventional bentonite or grout sealing procedures (see paragraph 3.3). The instrument shall be packaged such that these procedures can be used. Special attention shall be paid to prevention of a water bypass through or around the seal along the extensometer part of the borehole linkage. Special attention shall also be paid to the facility with which a seal or packer may be placed, and appropriate sealing procedures shall be recommended for the adopted instrument designs. These procedures shall make use of tamped bentonite pellets, tamped bentonite "donut" molds, bentonite/cement or chemical grouts, or other suitable material.

4. If Arrangement 'A' (Fig. G-4) is adopted, packaging arrangements and installation procedures shall, if practicable, permit installation using emplacement rods alongside the borehole linkage, thereby overcoming the need to thread the borehole linkage through emplacement rods during installation. If emplacement rods are alongside the borehole linkage, they shall be E-size drill rods or equivalent. Connection to the instrument head shall be by a left hand thread. Recognizing the requirement for installation to be possible within a 2-3/8 borehole, the borehole linkage shall fit within the remaining space.

Extensometer rod shall be 1/4-inch flush coupled stainless steel. The extensometer rod sleeve shall be 1/2- by 3/8-inch polyethylene tubing.

The piezometer standpipe shall be nylon or polyethylene, with maximum inside diameter 0.2 inch.

The oil line for actuating the anchor shall be 3/16-inch outside diameter Type "H" nylon pressure tubing.

The extensometer rods shall connect to the instrument head with a bayonet or similar fitting such that they can be disconnected, removed and reconnected at any time to ensure free sliding within the sleeve.

The external sleeve shall surround all tubes, either bunched together or in ribbon form. The sleeve shall be tough, flexible, waterproof and abrasion resistant. It shall be sealed to the instrument head such that the connection will withstand 100 psi water pressure.

The connection between all tubes, sleeve and instrument head shall be strong enough to withstand a 100-lb tensile pull.

The borehole linkage shall be such that it can be coiled for shipment in a coil of diameter no larger than 3 feet 6 inches with all connections completed to the instrument head except extensometer rod, and all tubes cut to length. Removable plugs shall be provided for the oil line, extensometer rod sleeve and piezometer standpipe.

5. If Arrangement 'B' (Fig. G-5) is adopted, the extensometer pipe sleeve also serves as emplacement rods.

The extensometer and sleeve pipe shall both be black steel pipe, threaded and coupled in 5- or 10-foot lengths. The extensometer sleeve shall be standard (Schedule 40) and the pipe extra heavy (Schedule 80).

6. The surface enclosure shall be of mild steel, cast-iron, precast concrete or other suitable material to withstand traffic. The depth shall be sufficient to accommodate the 18-inch extensometer travel and the width or diameter sufficient to allow easy installation of its contents.

7. The surface enclosure cover shall have a vandal-proof closure arrangement, and shall be sufficiently sealed internally and externally, or drained, such that surface water does not pass down the boring.

4.6 <u>Extensometer for Inaccessible Instrument</u>

1. The extensometer for the inaccessible instrument shall be a rod extensometer using a linear potentiometer, variable reluctance linear transducer or linear variable displacement transformer (LVDT).

2. The linear position sensor shall have the following characteristics:

(a)	Range:	18 inches
(b)	Sensitivity:	± 0.1 inch
(c)	Linearity:	± 0.5 percent
(d)	Shock Survival:	50 g of 11-ms duration, half sine wave

(e) Vibration Survival: 25 g RMS 20 Hz to 2 kHz random.

(f) Temperature Range: -40°F to 200°F

(g) Temperature Sensitivity: 0.03 percent per °F

3. The linear position sensor, cable and terminal connector shall be adequately sealed against moisture such that the sensor will function correctly over a 12-month period when subjected to 20 psi external water pressure.

4. Anchor and rod length requirements as indicated in paragraph 4.3 apply.

4.7 Piezometer for Inaccessible Instrument

1. The piezometer sensor for the inaccessible instrument shall be a diaphragm type electrical transducer. A piezometer of this type is illustrated in Fig. G-6. (Wissa et al, 1974)

2. The pressure transducer shall have the following characteristics:

(a) Range:	0 to 100 psi
(b) Accuracy:	±1 percent of full scale (User Calibration to 0.1 percent required)
(c) Sensitivity:	±0.1 psi
(d) Repeatability:	±0.05 psi
(e) Shock Survival:	50g of 11-ms duration; half sine
(f) Vibration Survival:	25g RMS 20 Hz to 2kHz random
(g) Temperature Range:	-40°F to 200°F
(h) Temperature Sensitivity:	0.03 percent per °F

3. The maximum outside diameter of the pressure transducer cable shall be 3/16 inch.

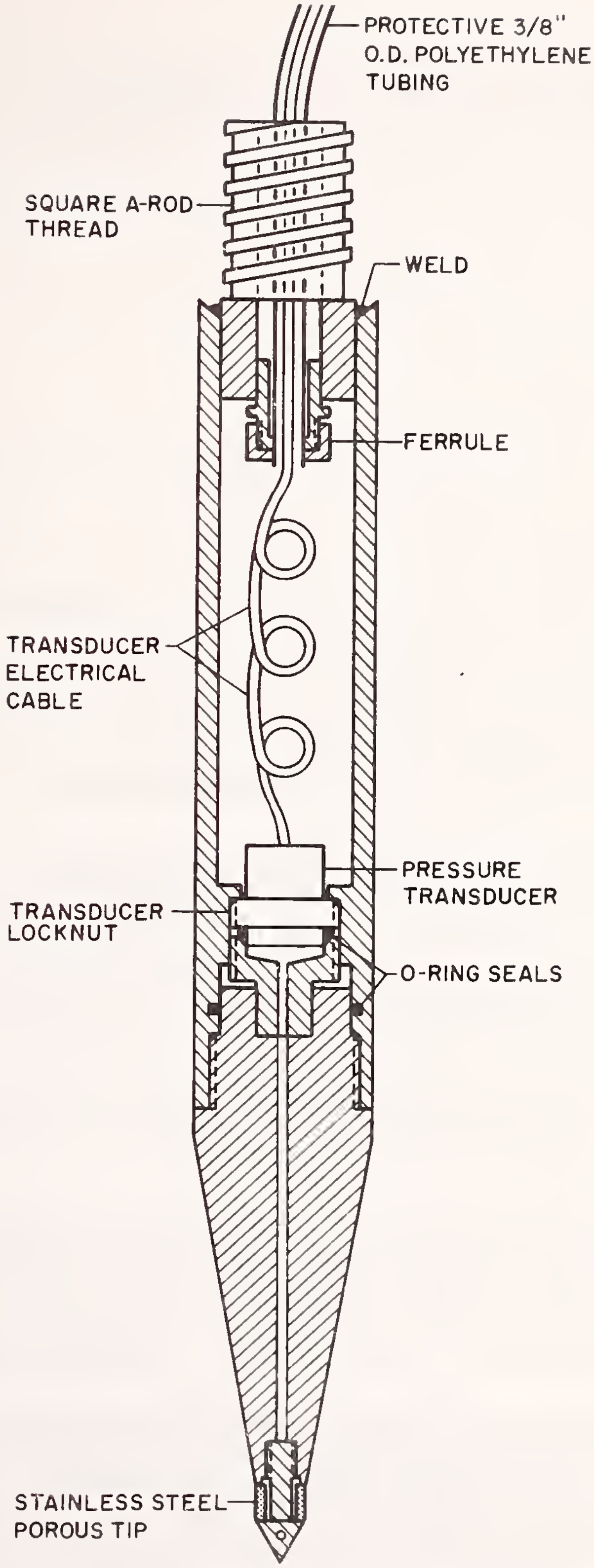

Figure G-6. Pressure Transducer Piezometer

4. The pressure transducer, cable and terminal connector shall be adequately sealed against moisture such that the pressure transducer will function correctly over a 12-month period when subjected to 100 psi external water pressure.

5. Arrangements shall be made whereby any air is excluded or allowed to escape from the line between porous filter and pressure transducer diaphragm.

6. The piezometer filter shall have a pore size of approximately 2 microns.

4.8 <u>Packaging for Inaccessible Instrument</u>

1. If Arrangement 'A' (Fig. G-4) is selected for the accessible instrument, the inaccessible instrument shall follow the same basic arrangement. Likewise, if Arrangement 'B' (Fig. G-5) is selected, that basic arrangement shall be followed for the inaccessible instrument.

2. The electrical pressure transducer shall replace the open standpipe piezometer shown in Figs. G-4 and G-5, and the transducer cable shall replace the piezometer standpipe.

3. The extensometer rod or pipe shall be as shown in Figs. G-4 or G-5 except for packaging within the surface enclosure. Within the surface enclosure the brackets holding the linear position sensor to the wall of the surface enclosure shall be sturdy, and adjustable so that the sensor may initially be set to read either at the extreme end of its extension range or 6 inches from this point, or at any point in between.

4. All appropriate requirements of paragraph 4.5 shall apply to the inaccessible instrument.

5. Electrical cables for pressure transducer and linear position sensor shall pass through a side exit in the surface enclosure, through suitable conduit and terminate in a remote readout box. The remote readout box may be assumed to be located in a sidewalk with its cover flush with the sidewalk surface.

6. The remote readout box shall have a vandal-proof closure arrangement, and shall have a drain to permit removal of any water that accummulates in the box.

7. The cables for pressure transducer and linear position sensor shall be packaged such that no field splices are necessary. Each cable shall be provided with a separate terminal connector having a removable waterproof cover. The connectors shall be of a size such that they can be pulled through the conduit between surface enclosure and remote readout box.

8. The linear position sensor shall be so arranged that reading correctness can be verified by mechanical means.

9. All O-ring seals shall use two O-rings.

10. The readout equipment for the pressure transducer and linear position sensor shall be packaged in a single lightweight portable unit.

4.9 Installation

1. Installation shall be possible through all soft ground materials, including boulders. In particular, provision shall be made to set the extensometer anchor in a boulder.

2. Installation shall be possible to depths of 160 feet.

3. Installation procedures shall permit the boring to be used for normal site investigation sampling, stratigraphy definition, logging and in-situ testing.

4. Boring shall be possible using equipment currently owned by the average boring contractor.

5. The installation procedure for the accessible instrument shall, if Arrangement 'A" is adopted, be generally along the following lines:

(a) Advance a boring using casing, hollow stem auger, wire line drilling techniques or degradable drill mud.

(b) Attach emplacement rods to the instrument head using a left hand thread.

(c) Insert instrument into boring to correct depth by driving or pushing as necessary (note that if the instrument head is to be installed in a material which permits pushing or driving, the boring should be advanced only to a level from which the instrument can be pushed into place, thereby facilitating piezometer sealing). If the material does not permit pushing or driving, the boring should be advanced to the instrument elevation. In that case, it may be necessary to seal the piezometer in place using a sealing procedure as discussed in paragraph 4.5 above.

(d) Actuate the anchor and cut the oil line.

(e) Disconnect and pull emplacement rods.

(f) Pull boring casing, wire line rods or augers.

(g) Fill the extensometer rod sleeve with oil.

(h) Insert extensometer rod and connect to instrument head.

(i) Install surface enclosure.

6. The installation procedure for the accessible instrument shall, if Arrangement 'B' is adopted, be generally along the following lines:

(a) Advance a boring using casing, hollow stem auger, wire line drilling techniques or degradable drill mud.

(b) Insert instrument into boring to correct depth (refer to paragraph 5 (c) above).

(c) Actuate the anchor by driving on the extensometer pipe while pulling on the piezometer standpipe to prevent it from being crimped at the anchor location.

(d) Disconnect the extensometer pipe sleeve at the left hand thread and raise the pipe 2 feet.

(e) Pull boring casing, wire line rods or augers.

(f) Install surface enclosure.

7. The installation procedure for the inaccessible instrument shall be generally along the lines specified in paragraphs 5 and 6 above for the accessible instrument, with the addition of the following:

(a) Attach linear position sensor to the extensometer rod or pipe and to the side wall of the surface enclosure. Adjust to initial setting.

(b) Install remote readout box and conduit.

(c) Snake cables through conduit to remote readout box.

4.10 Data Handling

No work shall be performed under this contract to develop and specify data handling procedures. Data will be obtained using manually operated portable instruments together with conventional optical survey procedures. Data will be written on standard field data sheets and processed either manually, using a desk calculater to assist with computations, or using the DAPSOG program (Data Processing System for Soft Ground Tunnel Construction Monitoring) described in Appendix F.

5. DELINEATION OF TASKS

The work to be performed under this contract shall include the following tasks:

Task A. Design of Instruments, Laboratory Testing, Design of Field Testing Program

1. Design and prepare detail drawings of one model of accessible and one model of inaccessible instrument.

2. Document the considerations given in making a selection of design.

3. Furnish one complete set of electrical components, comprising pressure transducer, linear position sensor, cable connectors, and indicating units. Conduct laboratory tests to ensure compliance with the requirements of paragraphs 4.6 and 4.7 and Appendix A.

4. Detail proposed field program for trial installation and testing of accessible and inaccessible instruments.

5. Submit to the technical monitor an interim report summarizing the results of Task A.

Task B. Hardware Fabrication and Field Testing

Subject to review and acceptance of the work completed under Task A, the contractor shall proceed with the fabrication and field testing program as described below:

1. Fabricate three prototypes of the accessible and three of the inaccessible instruments.

2. Select site or sites for field testing of the six instruments. The sites shall be in an environment where settlement is taking place and where groundwater conditions are changing. Priority consideration shall be given to an urban soft ground tunnel under construction.

3. Install, at each of three locations, a cluster of instruments. The cluster shall consist of one accessible instrument, one inaccessible instrument, one conventional open standpipe piezometer and one conventional rod extensometer or anchor post.

4. Read all instruments while pore pressure is changing and settlement is occurring. Evaluate adequacy and performance, giving consideration to comparative readings and comparative costs between instruments within each cluster and between clusters.

Task C. Amendments and Refinements to Hardware and Procedure

Make necessary amendments or refinements to hardware or installation procedures in accordance with results of field trials, and conduct additional field trials as necessary to document suitability of the hardware and installation procedures.

Task D. Preparation of Production and User Data

1. Develop production drawings and specifications for the two models of instrument, in accordance with Appendix A.

2. Prepare a brief and concise manual in accordance with Appendix A, describing theory of operation, installation procedures, reading procedures, faultfinding, data calculation procedures and maintenance procedures.

3. Prepare brief guidelines for appropriate usage of the instruments on tunnel projects, including estimated user costs.

REFERENCE

Wissa, A.E.Z., Martin, R.T., and Garlanger, J.E., The Piezometer Probe, Draft of paper to be submitted to the ASCE Journal of the Geotechnical Engineering Division, 1974.

APPENDIX H

REPORT OF INVENTIONS

Attention is directed to sections 6, 7, and 8 and appendixes F and G where concepts which will improve general systems monitoring are found.