GEOTECHNICAL INSTRUMENTATION AND MONITORING PLAN

S.P. 8580-149 (T.H. 90)
Dresbach Bridge Replacement and Interchange Project
Dresbach, Minnesota

Report No. 01-05719

Date:

April 30, 2013

Prepared for:

Ames Construction, Inc.
2000 Ames Drive
Burnsville, Minnesota 55306

AMERICAN ENGINEERING TESTING, INC.

CONSULTANTS
• ENVIRONMENTAL
• GEOTECHNICAL
• MATERIALS
• FORENSICS

April 30, 2013

Ames Construction, Inc
2000 Ames Drive
Burnsville, Minnesota 55306

Attn: Mr. Benjamin Lovin
Construction Project Manager

RE: Geotechnical Instrumentation and Monitoring Plan
S.P. 8580-149 (T.H. 90)
Dresbach Bridge Replacement and Interchange Project
Dresbach Minnesota
AET Project No. 01-05719

Dear Mr. Lovin:

American Engineering Testing, Inc. (AET) is pleased to submit the Geotechnical Instrumentation and Monitoring Plan (GIMP) for monitoring embankment response to planned construction activity. Work covered in this plan shall consist of furnishing and installing a geotechnical monitoring and instrumentation system for the west approach embankment for the Interstate 90 river bridge crossing at Dresbach, Minnesota.

These services were performed according to our proposal to you, dated October 17, 2012.

We are submitting 3 copies of the report to you.

Please contact me if you have any questions about the review or if I can be of further assistance.

Sincerely,
American Engineering Testing, Inc.

Joseph G. Bentler

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SIGNATURE PAGE

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Mr. Benjamin Lovin

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Authored By:

Joseph G. Bentler, P.E.
Senior Geotechnical Engineer

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.

Date: 4/30/13 **License #: 46214**

Reviewed By:

Joseph Korzilius, P.E.
Principal Engineer

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1.0 INTRODUCTION

Work covered in this Geotechnical Instrumentation and Monitoring Plan (GIMP) describes installation of a geotechnical instrumentation system for monitoring the performance of the west approach embankment for the Interstate 90 river bridge crossing the Mississippi River at Dresbach, Minnesota. The instrumentation installed is intended to monitor short and long term embankment performance (settlement and stability) due to the subsurface site conditions and the nature of the proposed construction activities.

Planned embankment construction includes installation of piles for support of retaining walls, staging of embankment fills and installation of geogrid reinforcement for slope stability. The design requirements and construction approach are intended to ensure embankment stability is at or above a minimum design factor of safety and that post construction settlements are at or less than acceptable levels.

2.0 OVERVIEW

Along the west bridge approach embankment the installation of instrumentation and our monitoring program will follow this GIMP developed from the Plans and Special Provisions for this project. This GIMP is applicable to embankment construction in the area that includes the west abutment for the new bridge extending west along the alignment for the access road AOI ACCESS Station 27+50 to Station 37+00. A similar instrumentation setup is proposed at each of three individual cross-sections along the access road alignment. These approximate cross-section locations are identified as AOI ACCESS Station 28+50, Station 31+00, and Station 34+50. On the attached plan sheet, Figure 1 at the end of this report, the approximate locations of instrumentation and cabinets, and alignment of horizontal shape array's and cables are shown. These cross-sections will also be referred to as Instrumentation Cross-Sections A, B, and C. This

plan sheet was developed in coordination with Ames Construction and based upon planned construction staging and operations. Adjustments to these locations may be made at the time of installation based upon field conditions encountered. Locations of instrumentation elements will be surveyed in by Ames Construction and identified with GPS coordinates for locating purposes.

Installation of instrumentation is planned after preliminary grading and site preparation has occurred and prior to major embankment construction. In order to facilitate installation and promote long lasting operation, we request all obstructions, topsoil, slope dressing and other organic material should be removed prior to installation of instrumentation. We understand some fill material may be placed prior to installation of instrumentation. This fill is not expected to extend above the approximate inplace ground line elevation, which is the approximate ground line elevation shown in the plans.

To the extent possible, instrumentation will be installed after pile driving operations along Wall S to avoid potential damage to instrumentation and cabling.

Along the defined instrumentation section that extends beneath the west abutment, instrumentation cables and the horizontal shape array will need to be installed prior to pile driving for the west abutment because a considerable amount of fill must be placed prior to abutment pile installation. Our plan is to install instrumentation just behind the front row of battered pile which we expect to provide adequate clearance. For this reason, the actual AOI ACCESS Station for this instrumentation cross-section “A” will be closer to Station 34+00.

Based upon our discussions with the instrumentation manufacturer, pile driving that does not contact instrumentation should not interfere with the long term operation of the instrumentation; short term noise may be observed in instrumentation readings as pile driving is ongoing.

After installation of instrumentation and initialization, collected data will be digitally recorded. A secure website will be created to allow data to be accessed and viewed by MnDOT in near real time. AET will monitor installed sensors and maintain the website through project completion. MnDOT will monitor sensors and maintain the website after final project acceptance.

3.0 QUALIFICATIONS OF PERSONNEL

MnDOT Special Provisions require a Professional Engineer (Civil) registered in the State of Minnesota to oversee this work. Also required are a minimum of 5 years of recent geotechnical experience with instrumentation of multiple instrumentation projects and at least 7 hours of recent continuing education on geotechnical instrumentation. Joseph G. Bentler, P.E. will direct and oversee installation and monitoring of this instrumentation. Refer to Appendix A for Mr. Bentler's resume and certificate providing verification of the required training.

4.0 SUBSURFACE INVESTIGATION

The design phase of the project included numerous SPT borings and CPT soundings in the west approach embankment, Wall U, and Wall S areas. No additional subsurface exploration is planned to be performed prior to our instrumentation field work. However, many of the sensors will require that boreholes be drilled for their installation. Some of these boreholes will include split spoon sampling per requirements given in the Special Provisions to identify a particular fine alluvium layer. Boreholes for piezometers and/or settlement systems will be continuously

sampled by split spoon in the elevation range from 640 to termination depth with the intent to identify the depth and extent of a fine alluvium layer. This soil layering information will be used in the field to determine the depth of sensor installation appropriate for measuring pore water pressures or settlement. This field determination is discussed further in Sections 5.1 and 5.4 for piezometers and borehole settlement systems, respectively. For those installation borings that include soil sampling, a soil boring log conforming to MnDOT requirements (other than with respect to normal sampling intervals and/or lab testing) will be generated.

5.0 INSTRUMENTATION

Six types of electronic sensors are proposed to be installed to monitor embankment performance; these are discussed in the following sections. For the more significant elements of the instrumentation system, we have attached manuals and documentation that include more complete descriptions and specifications of the sensors. Refer to Appendix C. Instrumentation will be in close conformity with the MnDOT Plans and Special Provisions and this report.

5.1 Vibrating Wire Piezometers

Geokon Model 4500S, installed by "fully grouted method"
100 psi
Cable (Total length: TBD, approximately 4800 feet ordered)

Specifications	
Range	1, 2, 3 MPa (100 to 350 psi)
Over Range	2 × rated pressure
Resolution	0.025% F.S.
Accuracy	±0.1% F.S.
Linearity	<0.5% F.S.
Temperature Range	−20°C to +80°C
Length × Diameter	133 × 19.1 mm

5.2 Vibrating Wire Earth Pressure Cell

Geokon Model 4800 VW Earth Pressure Cell
100 psi range
Cable (Total Length: TBD, 3650 feet ordered)

Specifications

Range 100 psi
Over Range 150% F.S.
Resolution ±0.025% F.S.
Calibrated Accuracy ±0.1% F.S.
Temperature Range −20°C to +80°C
Height × Diameter 6 × 230 mm

5.3 Vibrating Wire Biaxial Tiltmeters

Geokon Model 6350 VW Tiltmeters
Two uniaxial tiltmeters will be installed at each specified biaxial tiltmeter location using a biaxial mounting bracket manufactured by Geokon for that purpose.
Cable (Total Length: TBD 1850 feet ordered)

Specifications

Ranges ±10 degrees
Resolution ±0.05 mm/m (8 arc seconds)
Accuracy ±0.1% F.S.
Temperature Range −20°C to +80°C
Length × Diameter 172 × 32 mm

5.4 Borehole Vibrating Wire Settlement System

Geokon Model 4600 VW Borehole Settlement Systems with grouted anchor
165 feet of fluid tubing (estimated 20 to 35 feet per installation)
1950 feet of cable

Specifications

Ranges ≤ 7 meters
*Resolution ±0.05% F.S.
Accuracy ±0.1% F.S.
Temperature Range −20°C to +80°C
Length × Diameter *Reservoir*: 305 × 60 mm
Sensor: 191 × 35 mm

* Resolution is below specification requirements of 0.005% but still more precise than the specified accuracy. Accuracy of ±0.1% F.S. is per the specification requirements.

5.5 SAAF (Shape Accel Array) Sensors

Automated Horizontal Shape Deflection Monitoring Device – SAAF sensors manufactured by Measurand, Inc.

Specifications	
Segments	rigid; 50-cm (1.64-ft) lengths with flexible joints
Casing	Flexible PVC (1-inch dia. Schedule 40)
Resolution/Stability	+/- 0.5 mm / 32m SAA
Angular range of joints	45 degrees
Accuracy/Repeatability	1.5 mm / 32 mm
Active Length × Diameter	52 to 92 meters × less than 1.0 inch nominal
Accelerometers	temperature calibrated MEMS, triaxial (3D)
Minimum Sample Frequency	1 Hz

5.6 Vertical Inclinometers

Vertical Inclinometers will consist of SAAF sensors manufactured by Measurand, Inc. installed within 1-inch diameter Schedule 40 PVC electrical conduit grouted within a vertical borehole.

Specifications	
Casing	Flexible PVC (1-inch dia. Schedule 40)
Resolution/Stability	+/- 0.5 mm / 32m
Sensor gage/segment length	30 cm
Accuracy/Repeatability	+/- 1.5 mm / 32 m

Vertical SAA sensors will also meet specifications of Section 5.5, except with segment length of 30 cm.

5.7 Instrumentation Enclosure Cabinet (Earth Station Enclosures)

Each Earth Station Enclosure will include related components (i.e. data acquisition system, system set-up, software, modem, modem service, and related support), be placed on and securely attached to concrete pads, and be lockable. For each Earth Station, a solar panel, solar regulator, and battery box will be included. The Earth Station will be able to operate in wet and dry weather conditions from -40F to 120F.

Specifications	
Power	Solar panel, with 50W panel and regulator
Connections	Instrument to DA system; DA to cell modem uplink
Uplink	Cellular Modem w/ data plan
Battery box	provided with enclosure
Data Logger	Campbell Scientific CR800 Datalogger
Lightning Protection	System with grounding lugs

5.8 Datalogger

Campbell Scientific CR800 will be utilized per SAAF sensor manufacturer's recommendations. Three CR800 dataloggers (one for each set of instrumentation at each of the three AOI ACCESS stations identified in the Special Provisions) will be installed. Each CR800 will be furnished with a 4-year manufacturer's warranty (from date of original purchase).

5.9 Cables

Data cables matching the appropriate sensors will be as recommended and provided by the manufacturer (e.g. Geokon Model 02-250V6 Blue PVC Signal Cable). Sensors will be ordered with sufficient connection cable to allow for 10 feet of additional cable in the cabinet. Data cables will conform to the requirements listed below:

Specifications	
Conductors	22 AWG (stranded 7 × 30 AWG) tinned copper
Conductor Insulation	Polypropylene, 10-Mil high density, color coded
Shielding	Aluminum polyester with drain wire, 24 AWG tinned copper
Jackets	Extruded PVC standard

5.10 Conduit and Accessories

Conduits and fittings used will be non-metallic and sufficiently robust to survive construction installation and backfilling activities. The use of Schedule 40 PVC electrical conduit is planned. We are prepared to install conduit having a diameter sized such that all electrical cables and

conductors to be installed within the conduit run and occupy not more than 40 percent of inside cross-sectional area. Sharp bends in conduit systems will be avoided.

5.11 Settlement Plates

Settlement plates closely conforming to MnDOT standard plan (Figure 2 included at the end of this report) are planned. PVC pipe sleeves having an approximate 2-inch outside diameter are planned to jacket around the nominal 1-inch diameter steel riser pipes of the settlement plates.

5.12 Documentation

After project acceptance the installed instrumentation will become MnDOT property. This includes instrumentation and automated monitoring/data acquisition devices. Copies of the sensor calibration certificates will be provided to MnDOT. Manufacturers' warranties and guarantees furnished for materials and electrical equipment, calibration sheets, instruction sheets, and parts lists supplied with materials and electrical equipment, shall be presented when requested by the Engineer.

6.0 CONSTRUCTION REQUIREMENTS AND INSTRUMENTATION INSTALLATION

A pre-installation meeting will be held at the site to coordinate details of the installation and monitoring work. Instrumentation groups, for the west approach embankment, are planned to be installed approximately at Station 28+50, Station 31+00, and Station 34+00 along the AOI ACCESS alignment. Approximate locations for instrumentation, cabling and enclosure cabinets are provided on a plan sheet at the end of this document (Figure 1). Adjustments to each location may be made based upon field conditions encountered. Any field change made to the final location will be coordinated with the contractor and MnDOT. Installation shall be such that all monitoring systems are protected from construction activities and may remain operable and in-place from the time of installation through the completion of the work. Based upon

construction staging and timing of installations, temporary cabinet locations may be utilized. These temporary locations may become final based upon MnDOT acceptance.

6.1 Anticipated Staged Construction Sequence

The following outlines the approximate planned and expected construction sequence:

1. Prior to installation of earth pressure cells and horizontal inclinometers, remove all topsoil and other organic material from areas where fill is to be placed. Fill material may be placed prior to installation of instrumentation. This fill is not expected to extend above the approximate inplace ground line elevation, which is the elevation shown in the plans prior to removal of topsoil or other material.

2. Pile driving and at least partial construction of Wall S is planned prior to installation of instrumentation. Conduit for cables will need to pass either below or through Wall S and both options have been discussed. The method employed will be determined based upon ground line elevations and construction staging at the time of installation, while still allowing a fixed vertical reference for the horizontal SAAFs. As a minimum, pile driving for Wall S will be completed within a 50-foot lateral distance of the instrumentation cross-section before installation begins at that cross-section.

<u>(Actual order of the following Items 3 through 7 may vary; several items will be accomplished concurrently over the course of an estimated two-week period beginning as soon as May 13, 2013.)</u>

3. Install earth pressure cells (EPCs) approximately at the inplace ground line elevation as shown in the plans. Sand Cover material will be provided to surround sensor installations

and earth pressure cells for protection. This sand cover will aid in establishing strain relief for connection cabling and general protection of sensors from construction distress and over-pressure/over-ranging. Large compaction equipment must not be used in the immediate area of the EPCs until at least 3 feet of backfill has been placed over the EPCs. The use of vibrating plate tampers is recommended in the vicinity of the EPCs.

4. Install horizontal SAAFs at the inplace ground line elevation as shown in the plans. Installation is planned after pile driving for Wall S has been completed, particularly within an approximate 50-foot lateral distance of the instrumentation cross-section. Care must be taken in the immediate area of installations and large compaction equipment must not be used in the immediate area of the SAAFs until at least 1.5 feet of backfill has been placed above them.

5. Install vertical SAAFs (those located directly behind Wall S), piezometers, and borehole settlement systems within boreholes.

6. Around the Rest Area Pond a temporary stability berm is planned in front of Wall S. Based upon our analysis the extent of the configuration of this berm can be altered from what is shown in the plans. What is required is a berm that follows the horizontal alignment of Wall S as it curves around the Rest Area Pond. The extent of the berm required includes tapering up from the front of Wall S from an elevation 2 feet above the top of footing toe to an elevation of 651 feet at a 1V:2H slope, provide for a 15-foot top width, then taper at a 1V:3H slope to meet the inplace ground line elevation. The Rest Area Pond must not be excavated within a nearly semicircular region extending out 80 feet from the front face of Wall S at AOI Station 28+44. This berm and configuration maintains the required factor of safety of 1.5 for global stability for the project. Our

analysis, and a plan view, and a cross-section based upon the above description are included in Appendix B.

The critical section for this reconfigured berm section is at the approximate location of one of our instrumentation groups, AOI ACCESS Station 28+50.

7. Complete construction of Wall S and install biaxial tiltmeters to front face. Install conduit and cable for future connections of vertical SAAFs to be installed from top elevation (661 feet) of Layer 1.

8. Upon completion of Wall S construction and successful installation of geotechnical instrumentation, a report showing baseline readings and indicating successful automated data acquisition setup will be provided to MnDOT.

9. Place and compact embankment fill for Layer 1 along entire length of Wall S. After placement of fill to elevation 661, the installation of settlement plates and remaining vertical SAAFs is planned. Placement of any additional fill will be delayed for approximately 2 weeks unless approval is given in writing by the MnDOT Engineer.

   Settlement plates are planned to provide information between the instrumentation cross-sections but primarily to serve as a mechanical reference to confirm the electronic instrumentation. Therefore, the settlement plate readings should not dictate the construction schedule.

   Due to the extent of fill planned to be placed for each Layer, the contractor estimates that it can take up to 2 weeks or more to place an entire Layer. Therefore, a reduction in the waiting period for portion(s) of an embankment layer may be requested based upon data

and analysis from instrumentation installed. In our opinion, monitoring data from the planned instrumentation layout (i.e. the 3 cross-sections) may facilitate approval of a portion of a Layer, which would consist of a half or a third of a Layer. The goal is that approval of a portion of a Layer by the MnDOT Engineer would allow placement of fill for the subsequent Layer over the approved portion of the first Layer with little or no pause in construction but still with adequate global stability provided.

10. After the appropriate waiting periods or written approval of the Engineer, Layer 3 construction may commence by placing fill to maximum elevation 698 feet. (North/west of AOI STA 25+00, Layer 3 construction will be to top of Wall U because top-of-wall elevation is 698 or less). In the area of the abutment, Layer 3 fill will be placed to elevation 698 above the future bottom elevation of Wall U to preload the abutment area and this portion of Wall U.

    After placement of Layer 3 fill, settlement plates shall be re-established. The placement of additional fill will be delayed for a minimum of 2 weeks and until approval is given in writing by the MnDOT Engineer. A reduction in the waiting period may be requested. Engineer's approval will be contingent on instrumentation indicating stable embankment construction.

11. After written approval of the Engineer, Layer 4 construction may commence and be completed. In the area of the abutment, Layer 4 fill will be placed to elevation 717 to preload the abutment area and this portion of Wall U. After completion of Layer 4 construction to maximum elevation 717 settlement plates shall be re-installed. An up to 4 week waiting period is expected. The placement of additional fill will be delayed until approval is given in writing by the MnDOT Engineer. A reduction in the waiting period

may be requested. Engineer's approval will be contingent on instrumentation indicating stable embankment construction.

After written approval of the Engineer, excavation needed to allow construction of the West Abutment and Wall U may commence.

For settlement plates, sets of 3 settlement plates will be placed along approximately 10 cross sections, spaced approximately 100 feet apart, along the AOI ACCESS ROAD alignment from Station 27+50 to Station 36+50. Plastic sleeves shall be provided around steel riser pipes of the settlement plates to prevent adhesion of soil and frozen soil. Settlement plates shall be surveyed using non-GPS, total station-type survey equipment with minimum 0.01-foot field accuracy and tied to a minimum of 3 fixed-elevation benchmarks. Benchmark monuments will be created to achieve the fixity of elevation. The settlement plates are expected to provide information between the instrumentation cross-sections and to serve as a reference check for the electronic instrumentation. They should not dictate construction schedule.

6.2 Instrumentation Installation

We anticipate our instrumentation installation to include 12 earth pressure cells, 12 piezometers in 12 boreholes, 3 "reference" piezometers buried in sand at existing grade, 6 borehole settlement systems in 6 boreholes, 6 biaxial tiltmeters, 3 horizontal SAAF sensors, 6 vertical SAAF sensors, and 30 settlement plates. Given the close proximity (10 feet apart) of pairs of the earth pressure cells and the piezometers, AET assumes each successfully installed pair will constitute one level of redundancy if sensor malfunction(s) were to occur following burial of sensors at the start of staged embankment construction (i.e. if one of the paired sensors malfunctions following start of Layer 1 construction, it need not be replaced).

Sensors will be installed in general accordance with manufacturer's recommendations and current "best practices" for geotechnical instrumentation. For example, vibrating wire piezometers will be installed by the "Fully Grouted Method" (identified in the Geokon manual for this sensor as "Installation Method C") and Earth Pressure Cells will be installed within "nests" of Sand Cover material. SAAF sensors manufactured by Measurand, Inc. are planned to be placed within 1-inch diameter Schedule 40 PVC electrical conduit. The horizontal sensors will be placed on the ground surface after topsoil, slope dressing, and/or other surface stripping has been performed. The cable-end of the SAAF sensors will be attached to the heel of the Wall S to provide elevation fixity. Vertical SAAF sensors will be installed down the PVC conduit after the conduit has been grouted within a drilled borehole.

The piezometers need to be installed such that each piezometer is isolated to indicate the ground water pressure at the specified locations and elevations. One borehole for each piezometer and settlement system group will be continuously sampled in the elevation range from 640 to termination depth, to identify the location of a fine alluvium layer expected to be encountered. Our intent is to install the borehole settlement sensors first (with continuous sampling from elevation 640 down to the termination depth), allowing for field identification of the fine alluvium layer. This info will then be used for targeting the depth of piezometer installation. Borehole settlement systems will be anchored 5 feet below the bottom of the fine alluvium where identified, estimated to be about elevation 620. A grouted anchor will be used. Ideally, each piezometer will be installed a minimum of 3 feet into the fine alluvium layer, unless the layer thickness is 6 feet or less, in which case the piezometer will be centered (± 1 foot vertically) within the fine alluvium layer.

Each biaxial tiltmeter installation will consist of two uniaxial tiltmeters attached to the front face of Wall S using a manufacturer-recommended biaxial bracket and enclosed within a protective

enclosure to keep direct sunlight, rain, snow, wind, and/or animals off the sensors. Ames Construction will need to provide AET with access to the top of Wall S for mounting the tiltmeters.

Sufficient length of sensor cables will be provided in an effort to minimize the need for field splicing, provide strain relief where large deformations can reasonably be expected and provide for approximately 10 feet of additional cable in the cabinet. Where needed, sensor cables will be installed within protective PVC conduit. Data cables from the piezometers and earth pressure cells may run adjacent to the Automated Horizontal SAAFs, but not closer than 2 feet to the sensors. Sensor cabling for all other sensors may run in the same conduit and trenches.

Each of the anticipated three Earth Station cabinets will be located in front of Wall S and outside the embankment fill. Earth Station cabinets will be placed at elevations above the 100-year flood level of the Mississippi River (assumed to be elevation 645.6 feet). Planned initial locations for data collection equipment cabinets and cable trenches will be as shown on attached Figure 1; final cabinet locations are planned to be at the face of Wall S or as coordinated with MnDOT. The instrumentation cabinets will be secured to concrete pads at the locations shown on Figure 1. Concrete pads will have one or more 4 inch PVC pipes installed in the base with a “90° sweep” bend below the concrete so that the pipes exit to the exterior of the cabinet to provide access for the sensor data cables.

Care must be taken in filling trenches and when backfilling over sensors to ensure that the potential for damage is reduced as much as possible. To prevent rodent infestation of the sensor cable conduit, the pipe ends will be packed with steel wool during the construction process.

AET will be responsible for sensor connections at the cabinet location and monitoring until substantial completion of the project. All sensors and Earth Station components including data collectors, cellular modems, power supplies and related equipment, such as solar regulators, will become MnDOT property after substantial completion of the project.

The locations of instrumentation, Earth Stations, cable runs, and cable splices will be identified within the final instrumentation plan as-built.

Water blended with bentonite clay will be used as drilling fluid. Neat cement grout may also be used and blended with cuttings and drilling fluid to seal boreholes as required by the Minnesota Department of Health regulations. Excess fluids will not be dumped into Waters of the State and will be managed such that fluids and cuttings are thinly spread over an area already disturbed by construction and worked into the soils.

7.0 INSTRUMENTATION MONITORING

Immediately after installation, sensors shall be checked and baseline readings obtained. Where necessary, field corrections for barometric pressure and ambient temperature will be made. One Earth Station is planned to be equipped with a barometer, and all three Earth Stations will have temperature measurements of the enclosure. This information will allow for site-specific environmental corrections for barometric pressure and ambient temperature. In addition, three "reference" piezometers of the same type and model as those specified will be installed within sand adjacent to an earth pressure cell at each instrumentation cross-section.

Monitoring of all electronic instrumentation will be hourly during staged embankment construction then daily for the first 2 weeks following completion of layer construction. (It is recognized that "continuous" staged embankment construction may result from possible MnDOT

Engineer's approval of portions of a given Layer for additional fill placement, and the data acquisition systems would need to monitor sensors hourly in such case.) Monitoring will continue weekly thereafter. With approval of the MnDOT Engineer, monitoring intervals may be reduced contingent on instrumentation indicating stable embankment construction.

Settlement plates shall be read daily during staged construction and for the following two weeks then weekly thereafter. With approval of the MnDOT Engineer, monitoring intervals may be reduced contingent on instrumentation indicating stable embankment construction.

In order to continue monitoring instrumentation after contract completion, all instrumentation purchased for this contract will become MnDOT property. This includes instrumentation and automated monitoring/data acquisition devices, cabinets, and solar power source equipment.

Electronic copies of sensor calibration certificates will be provided to MnDOT for all installed instrumentation upon request and at final acceptance.

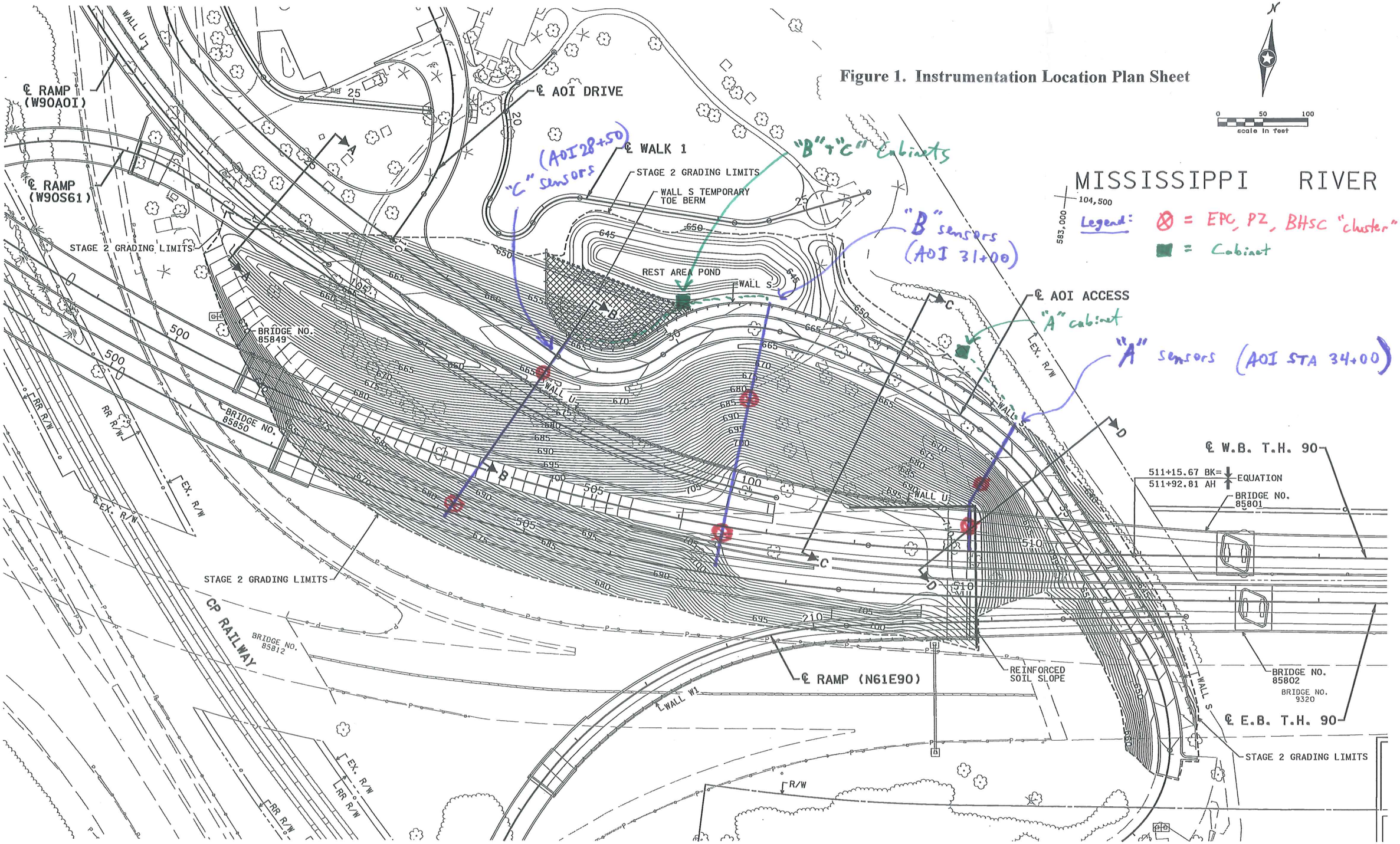
8.0 LIMITATIONS

Within the limitations of scope, budget, and schedule, our services have been conducted according to generally accepted geotechnical engineering practices at this time and location. Other than this, no warranty, either express or implied, is intended.

Figures

AET Project No. 01-05719

Figure 1 - Instrumentation Location Plan Sheet
Figure 2 - Settlement Plate Installation Detail



NO	DATE	BY	CKD	APPR	REVISION

...\cd8580149_dd18.dgn

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.

Print Name: CRAIG J. HASS

Date 7-27-12 License # 45039

DRAWN BY S. MARTINS
DESIGNED BY D. SYMANIETZ
CHECKED BY C. HASS
COMM. NO. 0107312

SRF Consulting Group, Inc.
ENGINEERS PLANNERS DESIGNERS

MINNESOTA STATE PROJECT NO. 8580-149
MINNESOTA STATE PROJECT NO. 8504-74
WISCONSIN I.D. 1071-05-74

MINNESOTA DEPARTMENT OF TRANSPORTATION

MISCELLANEOUS DETAILS
S.P. 8580-149 (T.H. 90)
STAGED PRELOAD EMBANKMENT (WEST ABUTMENT)

SHEET 160 OF 678

10:18:22 AM
7/26/2012
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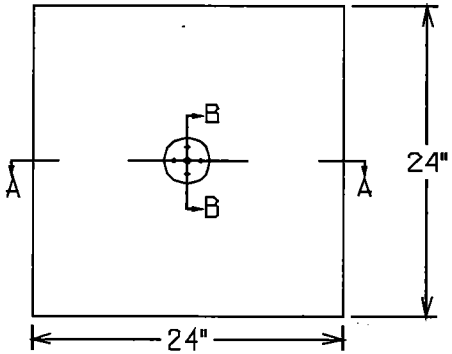
Figure 2. Settlement Plate Installation Detail

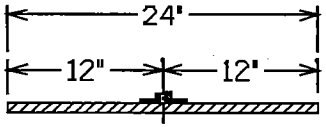
SETTLEMENT PLATE



PLAN VIEW

SETTLEMENT PLATE SHALL BE CONSTRUCTED OF ¾" PLYWOOD (EXTERIOR).

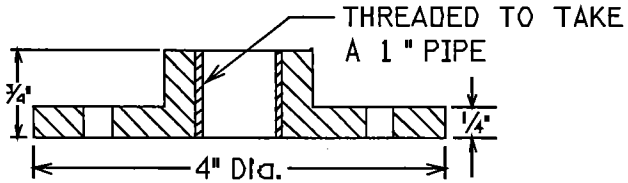
SECTION A-A



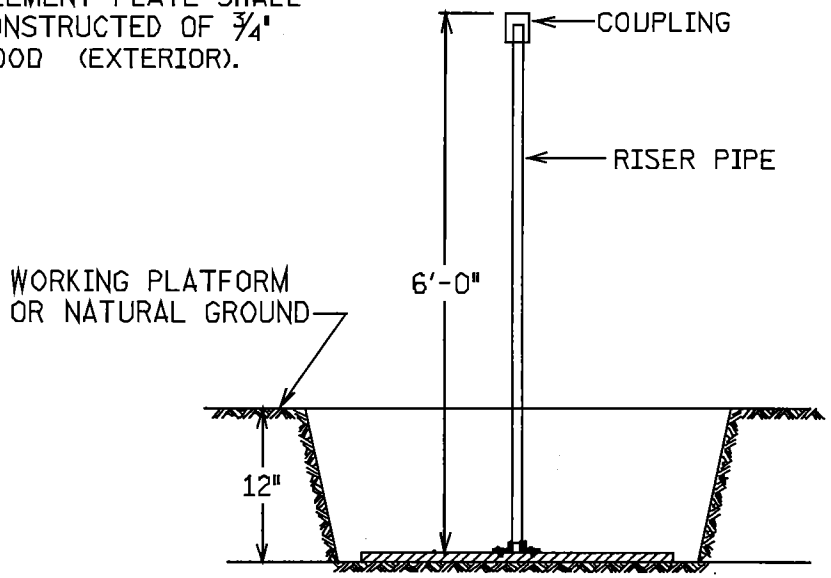
FLOOR FLANGE SHALL BE BOLTED TO THE PLATE WITH A MINIMUM OF THREE ¼" BY 1-1/2" BOLTS

SECTION B-B

STANDARD BLACK ¾" FLOOR FLANGE

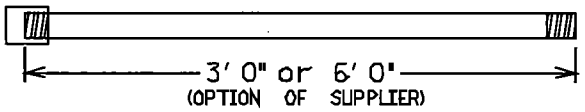


SETTLEMENT PLATE INSTALLATION



IN SEATING THE PLATE, THE 12" TRENCH SHALL BE BACKFILLED WITH GRANULAR BORROW (Mn/DOT Spec. 3149.2A) AND COMPACTED WITH ORDINARY COMPACTION (Mn/DOT Spec. 2105.3F2)

RISER PIPE & COUPLING



RISER PIPE SHALL BE A 1" STANDARD WEIGHT BLACK STEEL PIPE (ASTM A120)

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Appendix A

AET Project No. 01-05719

Resume, Joseph G. Bentler
Certificate of Verification of the Required Training

Joseph G. Bentler, PE

Senior Geotechnical Engineer, Geotechnical Division

Education

Master of Science, Civil Engineering
University of Minnesota, 2004

Bachelor of Science, Civil Engineering
University of Minnesota, 2002

Registrations/Certifications

Professional Engineer, Minnesota No. 46214, CO, MO, MT, OK, OR, and NE (Civil P.E.)

Employment

American Engineering Testing, Inc.
Staff to Senior Geotechnical Engineer, 2005 - Present
Staff Engineer I, Construction Services Department, 2004 - 2005

University of Minnesota
Grad/Undergrad Research Assistant, Department Of Civil Engineering, 1999 - 2004

Professional Memberships

American Society of Civil Engineers, Minnesota Section Board Member (2009 - Present)
Minnesota Geotechnical Society, ASCE Liaison (2005 – Present)
U of M Geotechnical Conference Planning Committee
Geo-Institute of ASCE, Local Involvement Task Force (2010), Local Involvement Committee (2011-2012) and Shallow Foundations Committee

Publications

Bentler, J.G. & Hoppe, M.J.L. SCPT for Design of Shallow Bridge Foundations in Minnesota. In *Proceedings of the 2nd International Symposium on Cone Penetration Testing, CPT '10* May 9-11, 2010.

Bentler, J.G., Dasenbrock, D.D. & Hoppe, M.J.L. Analysis and Performance Monitoring of a Spread Footing Bridge Foundation. In *Geotechnical Special Publication No. 187: Contemporary Topics in Ground Modification, Problem Soils, and Geo-support.* International Foundation Congress and Equipment Expo, Orlando, FL. March 2009.

Bentler, J.G. & Labuz, J.F. Daily and Seasonal Response of a Cantilever Retaining Wall. In *Geotechnical Special Publication No. 175: Proceedings of the 7th International Symposium on Field Measurements in Geomechanics* . Sept. 2007.

Bentler, J.G. & Labuz, J.F. Performance of a Cantilever Retaining Wall. *Journal of Geotechnical and Geoenvironmental Engineering*. Aug. 2006.

AET Responsibilities

- Engineering analysis and report preparation
- Geotechnical numerical modeling of stress, settlement, seepage, and slope stability
- Proposal preparation
- Planning, installation, and monitoring of geotechnical instrumentation
- Field testing (seismic ReMi and electrical resistivity)
- Coordination and supervision of CPT crew and CPT projects
- Project management

Project Experience

Central Corridor LRT System
Minneapolis to St. Paul, MN 2006-2012

Prepared work plan for field electrical resistivity testing, performed retaining wall foundation and overall stability analyses, and assisted in preparing Geotechnical Reports. Also performed settlement analyses and assisted in preparation of surcharging and instrumentation plan for the Operation and Maintenance facility track yard area. Installed, monitored (with automated data logging), and analyzed data from geotechnical instrumentation consisting of vibrating wire piezometers and settlement sensors during the period from December 2010 through April 2012.

Hardwood Creek Trail Overpass
Forest Lake, MN 2011 - 2012

Installed vibrating wire piezometers with automated data loggers as part of bridge approach embankment construction.

TH 23 over the Elk River
Forest Lake, MN 2011

Installed vibrating wire piezometers as part of staged construction of bridge approach embankment construction.

Lock & Dam 3 Design Build
Red Wing, Minnesota 2009 - 2010

Performed finite element analyses to model stresses and settlements resulting from construction of a guidewall embankment in the Mississippi River. Performed global stability analyses for the embankment, and computed reliability of embankment's geotechnical design according to USACE method.

TH 212 Design-Build
Eden Prairie to Chaska, MN 2005 - 2010

Prepared foundation analysis and design reports for retaining walls and embankments. Analyzed CPT data to make final design recommendations for noise walls. Installed and monitored geotechnical instrumentation and analyzed results. Assisted in planning and oversight of axial and lateral static pile load tests. Performed stress, settlement, and global stability analyses for retaining walls, bridge shallow foundations, embankments, lightweight fills, and slopes. Designed temporary reinforced soil slope for roadway bypass during construction.

Bren Road West over TH 169
Minnetonka, MN **2009 - 2010**
Conducted analysis of various foundation types for the abutments and center piers of a new, widened bridge at the interchange (including a final design incorporating both spread footings and driven piles for different substructures), authored the Geotechnical Exploration and Foundation Analysis and Design Report.

Retaining Wall Failure/Repair
Inver Grove Heights, MN **2009**
Prepared and directed soil boring and cone penetration test (CPT) work plan for exploration of geotechnical conditions at site of a failed mechanically stabilized earth (MSE) retaining wall. Conducted global stability analysis of the wall and made recommendations for repair/reconstruction of the failed/distressed portion of the wall.

Levee Certification/Improvements
Rushford, MN **2008 - 2012**
Prepared and directed soil boring work plan for evaluation of soil conditions below and landside of existing levees. Conducted slope stability, settlement, and seepage analyses and prepared Preliminary Geotechnical Reports assessing condition of levees with respect to Federal Emergency Management Agency (FEMA) levee certification process. Prepared and directed soil boring work plan for design of levee improvements (including 1000 feet of new levee) and underseepage mitigation to meet geotechnical criteria for levee certification. Performed final geotechnical analyses and prepared Final Geotechnical Report for design. Provided geotechnical review and managed soil testing during construction.

Steele County CSAH 7 Bridge over DM&E Railway
Owatonna, MN **2009**
Performed settlement and global stability analyses for new mechanically stabilized earth (MSE) retaining walls in front of the pile-supported bridge abutments and prepared recommendations for soil correction below MSE walls.

Lyndale Ave/I-494 Interchange
Richfield/Bloomington, MN **2007 - 2008**
Performed global stability and foundation analyses for new reinforced concrete cantilever retaining walls of the improved interchange and prepared Foundation Analysis Design Report (FADR) for the walls.

US Highway 2 Landslide Instrumentation
Crookston, Minnesota **2007 - 2008**
Assisted Mn/DOT with installation of automated slope monitoring sensors ("ShapeAccelArrays") at site of existing large landslide adjacent to US Highway 2 in Crookston.

Crosstown TH 62/I-35W Project
Minneapolis/Richfield, Minnesota **2007 - 2008**
As a subconsultant to the wall designer, performed global stability of mechanically stabilized earth (MSE) walls, including multi-level (tiered) walls.

TH 52 Oronoco Design-Build
Oronoco, MN **2006**
Performed slope stability analysis of new roadway embankments at Lake Shady. Analyzed CPT data to determine necessary surcharge duration following muck-out of organic soils.

TH 10/32 Design-Build
Hawley, MN **2005**
Made pile recommendations for design of TH 32 Bridge over TH 10. Performed slope stability analysis of ramp embankments using results of cone penetration test (CPT) soundings.

UNIVERSITY OF MINNESOTA

Twin Cities Campus

Department of Civil Engineering
College of Science and Engineering

122 Civil Engineering Building
500 Pillsbury Drive S.E.
Minneapolis, MN 55455

Phone: 612-625-5522
Fax: 612-626-7750
Website: www.ce.umn.edu/

This is to certify that

Joseph G. Bentler

Joseph G. Bentler

has participated in 7.5 Professional Development Hours (PDHs) at the

UNIVERSITY OF MINNESOTA

Geotechnical Instrumentation

short course on February 23, 2012 at the Continuing Education and Conference Center, Saint Paul Campus.

The short course, taught by Dr. Barry Christopher and Dr. Allen Marr, covered the following topics: calibration, maintenance and installation of instrumentation, collection of data, processing and presentation of collected data, interpretation of processed data, and reporting of results.

Joseph F. Labuz

Joseph F. Labuz, Ph.D., P.E.
Conference Director

Driven to Discover℠

Appendix B

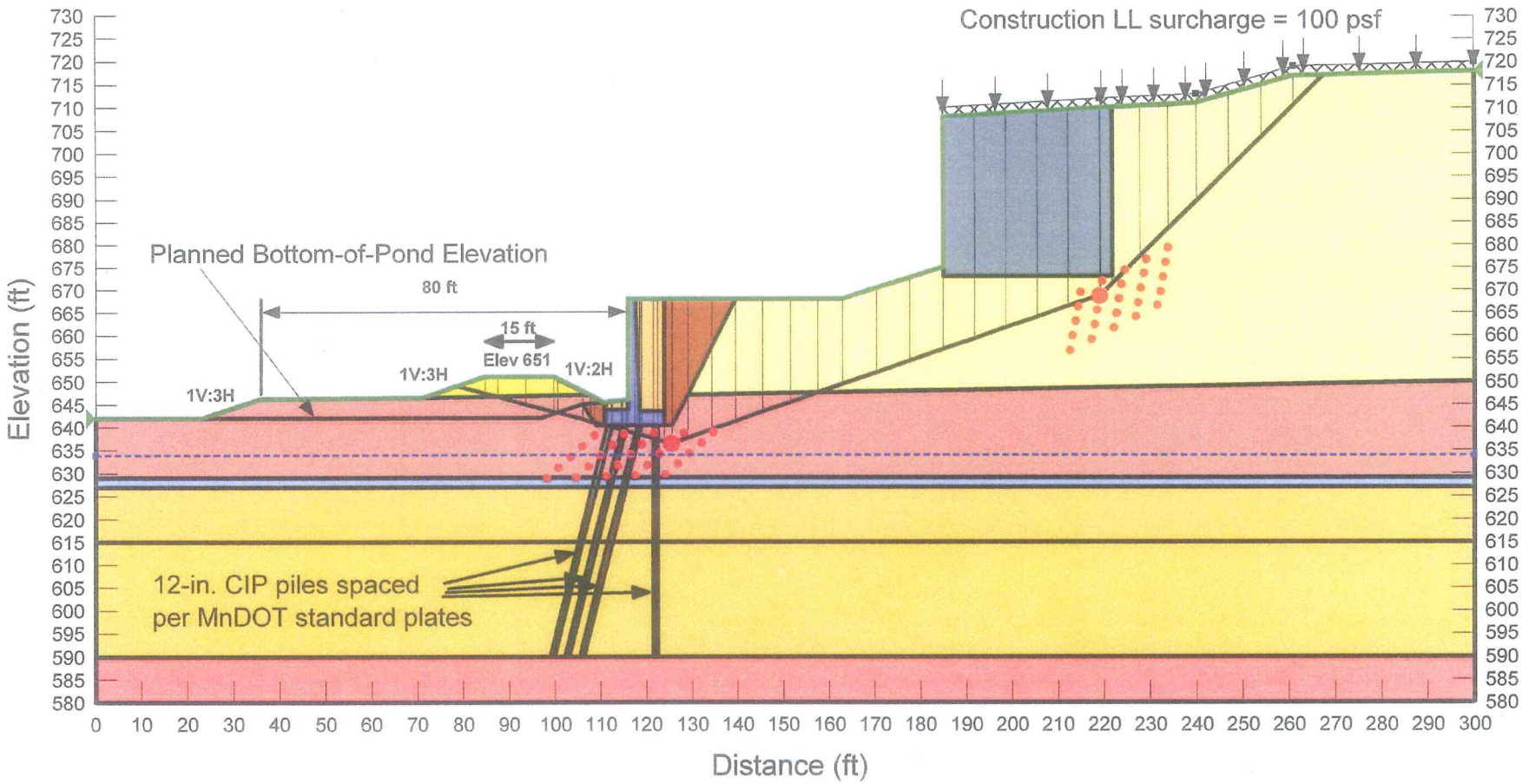
AET Project No. 01-05719

Rest Area Pond Stability Analysis Results
Rest Area Pond Stability Berm Configuration – Cross-section View
Rest Area Pond Stability Berm Configuration – Plan View

Dresbach Interchange - S, U Walls
AOI Station 28+44; Staged Preload
End of Stage 3; Effective Stress (Drained) Analysis

SLOPE/W 2007
Spencer's Method
AET No. 28-00319
J. Bentler
Date: 1/31/2012

Name: MSE Wall Unit Weight: 125 Cohesion: 50000 Phi: 60
Name: CIP Unit Weight: 1 Cohesion: 1e+005 Phi: 45
Name: Wall Backfill Unit Weight: 125 Cohesion: 0 Phi: 33
Name: New Embankment Fill Unit Weight: 125 Cohesion: 0 Phi: 33
Name: Existing Sand Fill Unit Weight: 120 Cohesion: 0 Phi: 32
Name: Fine Alluvium Unit Weight: 115 Cohesion: 0 Phi: 30
Name: Upper Coarse Alluvium Unit Weight: 120 Cohesion: 0 Phi: 32
Name: Middle Coarse Alluvium Unit Weight: 125 Cohesion: 0 Phi: 34
Name: Lower Coarse Alluvium Unit Weight: 125 Cohesion: 0 Phi: 36
Name: Wall Backfill over Heel Unit Weight: 1 Cohesion: 0 Phi: 33
Name: 12" CIP-Pile-toe Unit Weight: 125 Cohesion Fn: Wall S toe Phi: 0
Name: 12" CIP-Pile-middle1 Unit Weight: 125 Cohesion Fn: Wall S mid 1 Phi: 0
Name: 12" CIP-Pile-middle2 Unit Weight: 125 Cohesion Fn: Wall S mid 2 Phi: 0
Name: 12" CIP-Pile-heel Unit Weight: 125 Cohesion Fn: Wall S heel Phi: 0
Name: Sand Berm Unit Weight: 120 Cohesion: 0 Phi: 32



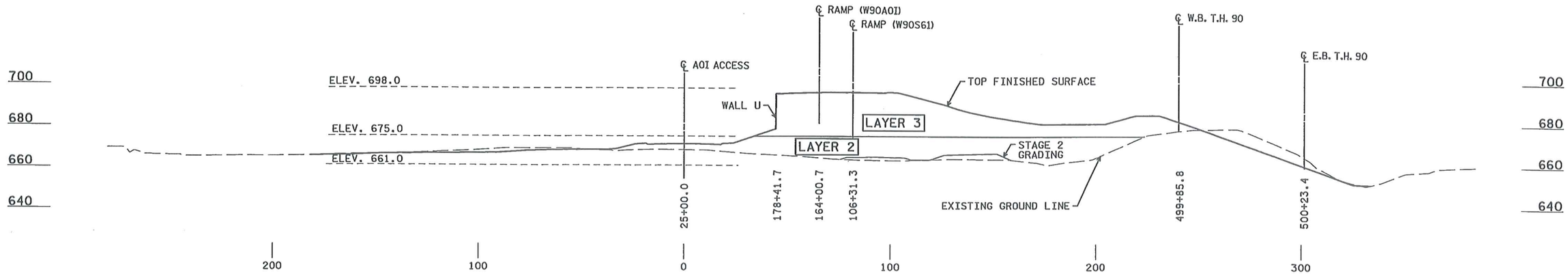
\\FILESERV2\users$\jbentler\28-00319 (Dresbach)\Slope Stability\LPILE\28+44\SU_STA_28+44_Stage 3_drained_overall_wedge_berm_revised.gsz

GENERAL NOTES:

SEE (2106) STAGED PRELOAD EMBANKMENT (WEST RIVER BRIDGE ABUTMENT) IN THE SPECIAL PROVISIONS FOR ADDITIONAL INFORMATION.

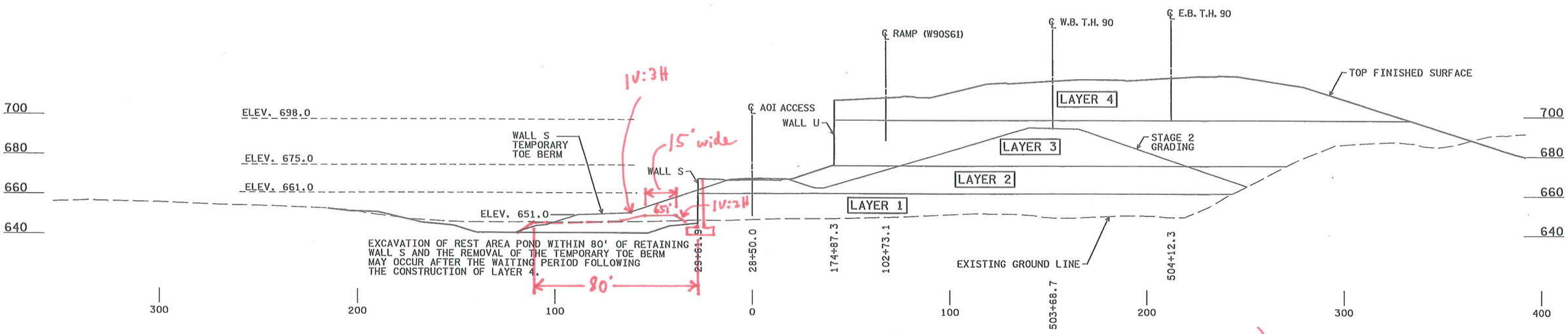
SEE (2011) EMBANKMENT MONITORING IN THE SPECIAL PROVISIONS FOR INFORMATION ON MONITORING REQUIREMENTS FOR THE WEST APPROACH EMBANKMENT.

FILL PLACEMENT SHALL NOT DEVIATE FROM THE LIMITS AND GEOMETRY SHOWN DUE TO GLOBAL STABILITY CONCERNS.



SECTION A - A

Rest Area Pond Stability Berm Configuration - Cross-section View



SECTION B - B (Approx. AOI ACCESS Sta 28+50)

NO	DATE	BY	CKD	APPR	REVISION
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I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.

Print Name: CRAIG J. HASS

Date 7-27-12 License # 45039

DRAWN BY S. MARTINS
DESIGNED BY K. MORTER
CHECKED BY C. HASS
COMM. NO. 0107312

SRF Consulting Group, Inc.
ENGINEERS PLANNERS DESIGNERS

MINNESOTA STATE PROJECT NO. 8580-149
MINNESOTA STATE PROJECT NO. 8504-74
WISCONSIN I.D. 1071-05-74

MINNESOTA DEPARTMENT OF TRANSPORTATION

MISCELLANEOUS DETAILS
S.P. 8580-149 (T.H. 90)
STAGED PRELOAD EMBANKMENT (WEST ABUTMENT)

SHEET 162 OF 678

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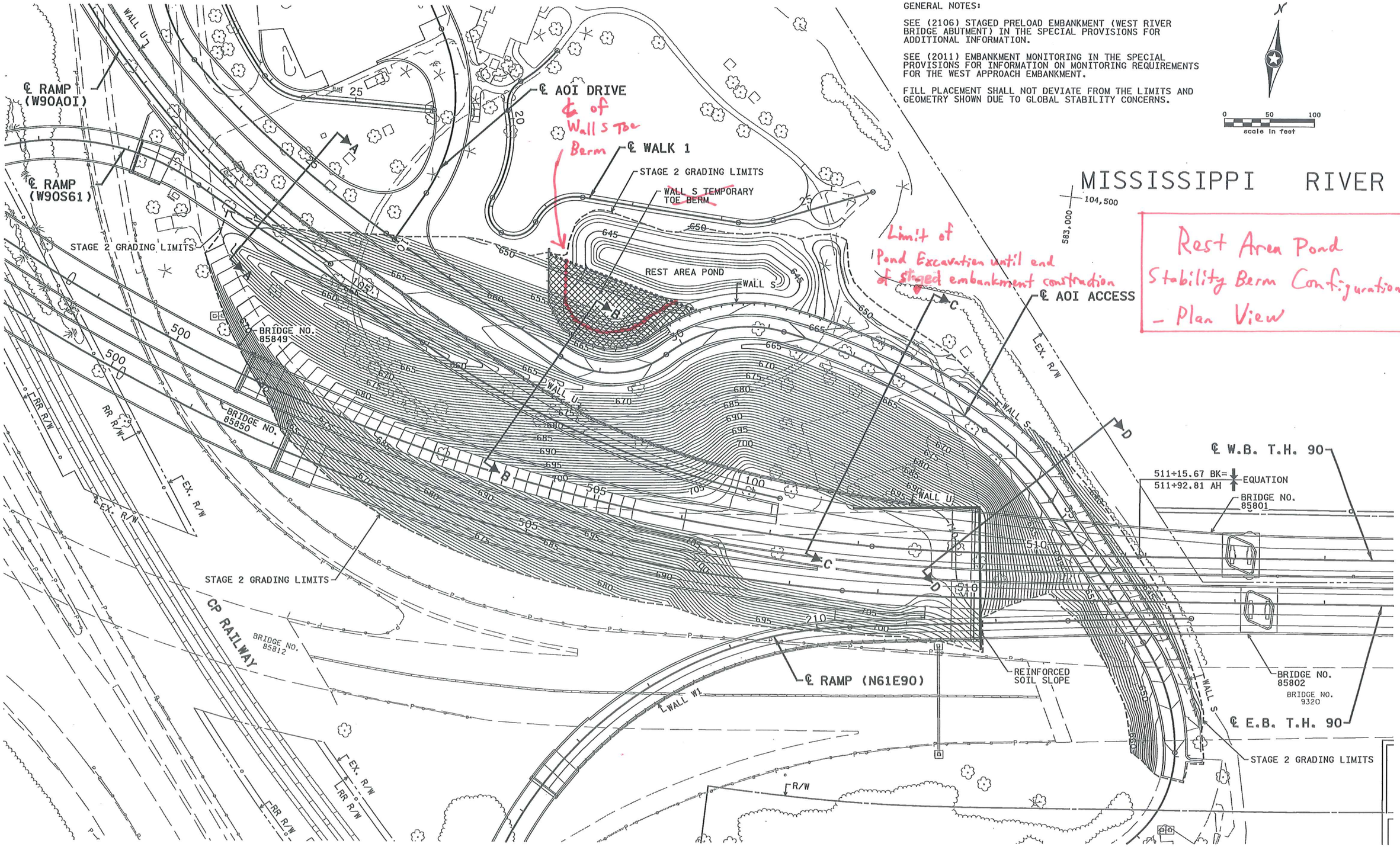
GENERAL NOTES:

SEE (2106) STAGED PRELOAD EMBANKMENT (WEST RIVER BRIDGE ABUTMENT) IN THE SPECIAL PROVISIONS FOR ADDITIONAL INFORMATION.

SEE (2011) EMBANKMENT MONITORING IN THE SPECIAL PROVISIONS FOR INFORMATION ON MONITORING REQUIREMENTS FOR THE WEST APPROACH EMBANKMENT.

FILL PLACEMENT SHALL NOT DEVIATE FROM THE LIMITS AND GEOMETRY SHOWN DUE TO GLOBAL STABILITY CONCERNS.



NO	DATE	BY	CKD	APPR	REVISION

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I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.

Print Name: CRAIG J. HASS

Date 7-27-12 License # 45039

DRAWN BY S. MARTINS
DESIGNED BY D. SYMANIETZ
CHECKED BY C. HASS
COMM. NO. 0107312

SRF Consulting Group, Inc.
ENGINEERS PLANNERS DESIGNERS

MINNESOTA STATE PROJECT NO. 8580-149
MINNESOTA STATE PROJECT NO. 8504-74
WISCONSIN I.D. 1071-05-74

MINNESOTA DEPARTMENT OF TRANSPORTATION

MISCELLANEOUS DETAILS
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STAGED PRELOAD EMBANKMENT (WEST ABUTMENT)

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Appendix C

AET Project No. 01-05719

Manuals and Guides for Instrumentation

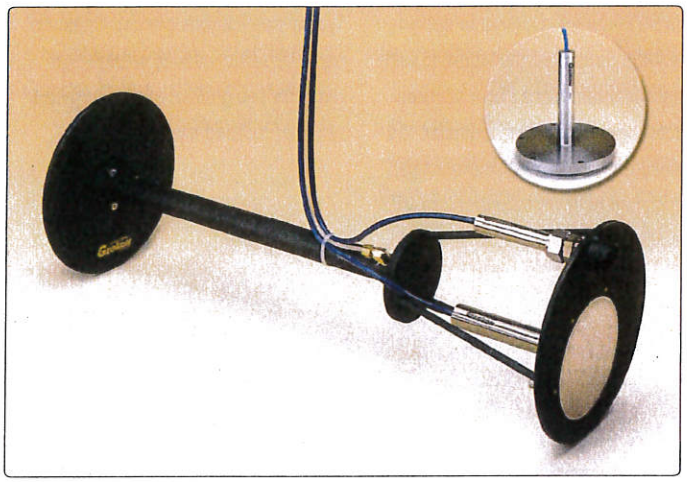
(OMITTED FROM PDF COPY FOR BREVITY)

Appendix C

AET Project No. 01-05719

Manuals and Guides for Instrumentation

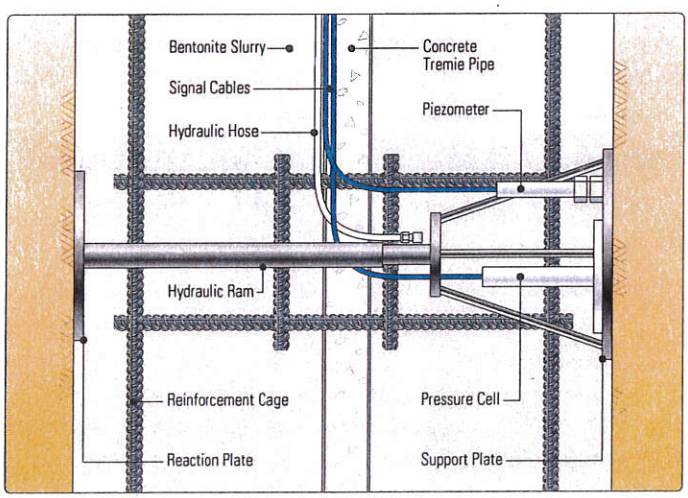
Model 4820 Jackout Pressure Cells



Model 4820 shown in hydraulic ram assembly with piezometer and alone (inset).

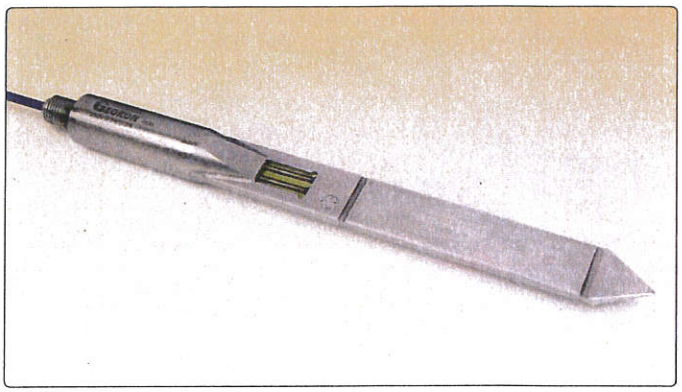
The Jackout Pressure Cell is designed for installation in diaphragm walls (slurry walls) to monitor soil pressures on the walls as excavation proceeds. This allows the build-up of excessive pressures to be detected in time to take remedial measures.

The Jackout Pressure Cell assembly consists of the cell mounted on a support plate, a reaction plate and a hydraulic ram. This assembly is attached, in its retracted position, to the reinforcement cage and is lowered into the slurry trench along with the cage. When the cage is in position the hydraulic ram is extended by means of a hand pump situated at the top of the wall and connected to the ram by a hydraulic hose. Pressure is applied forcing the reaction plate and the cell against the walls of the trench. This pressure is maintained while the concrete is tremied into the trench and until the concrete cures. The cell may be supplemented by a piezometer attached to the support plate to measure pore water pressures.



Jackout Pressure Cell assembly installed in diaphragm wall.

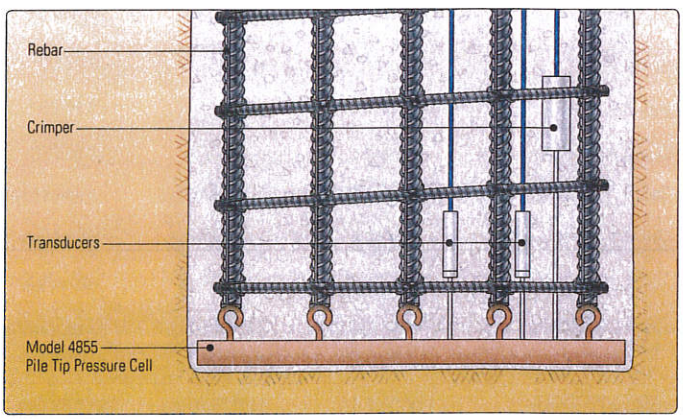
Model 4830 Push-In Pressure Cell



Model 4830 Push-In Pressure Cell.

The Model 4830 Push-In Pressure Cell is designed to be pushed in place for the measurement of total pressures in soils and earth fills. Where effective stress is required, the cell is fitted with an integral piezometer. A thread is provided on the end of the cell to allow for installation using lengths of pipe or drill rods. Models are also available (3500 Series) with semiconductor pressure transducers to enable measurement of dynamic pressures (please contact Geokon for details).

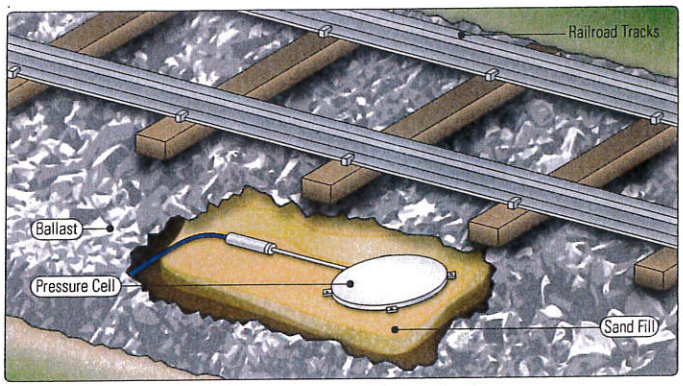
Model 4855 Pile Tip Stress Cells



Model 4855 Pile Tip Stress Cell installation

The Model 4855 Pile Tip Stress Cell is used to measure pile-tip loads in cast-in-place concrete piles (caissons). Like the Model 4810, the Pile Tip Stress Cell has a thick upper plate. The cell is manufactured to be close to the diameter of the pile and the back plate is supplied with hooks or sections of rebar to allow the cell to be connected to the bottom of the reinforcement cage. Two vibrating wire pressure transducers are connected to the cell to provide some redundancy in the event that one transducer is damaged during installation. An added feature is a remote "crimping" mechanism to allow the cell to be inflated slightly so as to ensure good contact between the cell and the surrounding concrete.

Model 3500 Series Earth Pressure Cells



Model 3500 Earth Pressure Cell installed under railroad tracks.

The 3500 Series is similar in design to the 4800 Series but the vibrating wire transducer is replaced by a semiconductor type transducer (to enable the measurement of dynamic pressures) which can have an output of 2 mV/V, 0-5 VDC or 4-20 mA.

Typical applications are the measurement of traffic induced stresses on roadway sub grades, airport runways or under railroad tracks.

Technical Specifications

	4800	4810	4815	4820	4830	4855	3500
Transducer Type	Vibrating Wire	Vibrating Wire	Vibrating Wire	Vibrating Wire	Vibrating Wire	Vibrating Wire	Semiconductor
Output	2000-3000 Hz	2000-3000 Hz	2000-3000 Hz	2000-3000 Hz	2000-3000 Hz	2000-3000 Hz	2 mV/V, 0-5 VDC or 4-20 mA
Standard Ranges[1]	70, 170, 350, 700 kPa; 1, 2, 3, 5, 7.5, 20 MPa	350, 700 kPa; 1, 2, 3, 5 MPa	350, 700 kPa 1, 2, 3, 5 MPa	350, 700 kPa; 1, 2, 3, 5 MPa	70, 170, 350, 700 kPa; 1, 2, 3, 5 MPa	3, 5, 7, 10.5 MPa	100, 250, 400, 600 kPa; 1, 2.5, 6 MPa
Over Range	150% F.S. (max)	150% F.S. (max)	150% F.S. (max)	150% F.S. (max)	150% F.S. (max)	150% F.S. (max)	150% F.S. (max)
Resolution	±0.025% F.S.	±0.025% F.S.	±0.025% F.S.	±0.025% F.S.	±0.025% F.S.	±0.025% F.S.	Infinite
Accuracy[2]	±0.1% F.S.	±0.1% F.S.	±0.1% F.S.	±0.1% F.S.	±0.1% F.S.	±0.1% F.S.	±0.5% F.S.
Linearity	< 0.5% F.S.	< 0.5% F.S.	< 0.5% F.S.	< 0.5% F.S.	< 0.5% F.S.	< 0.5% F.S.	< 0.5% F.S.
Thermal Effect on Zero	< 0.05% F.S.	< 0.05% F.S.	< 0.05% F.S.	< 0.05% F.S.	< 0.05% F.S.	< 0.05% F.S.	< 0.05% F.S.
Typical Long-Term Drift	< 0.02% F.S./yr	< 0.02% F.S./yr	< 0.02% F.S./yr	< 0.02% F.S./yr	< 0.02% F.S./yr	< 0.02% F.S./yr	< ±0.02% F.S./yr
Cell Dimensions[3] (H × D)	6 × 230 mm	12 × 230 mm	26 × 230 mm	12 × 150 mm	12 × 150 mm	600 × 50 mm	6 × 230 mm
Transducer Dimensions (L × D)	150 × 25 mm	150 × 25 mm	150 × 25 mm	150 × 25 mm	150 × 25 mm	(included in above)	150 × 32 mm
Excitation Voltage	2.5-12 V swept square wave	2.5-12 V swept square wave	2.5-12 V swept square wave	2.5-12 V swept square wave	2.5-12 V swept square wave	2.5-12 V swept square wave	10 V maximum
Excitation Frequency	1400-3500 Hz	1400-3500 Hz	1400-3500 Hz	1400-3500 Hz	1400-3500 Hz	1400-3500 Hz	n/a
Material	304 Stainless Steel	304 Stainless Steel	304 Stainless Steel	304 Stainless Steel	304 Stainless Steel	304 Stainless Steel	304 Stainless Steel
Temperature Range[1]	–20°C to +80°C	–20°C to +80°C	–20°C to +80°C	–20°C to +80°C	–20°C to +80°C	–20°C to +80°C	–20°C to +80°C

Note: PSI = kPa × 0.14503, or MPa × 145.03

[1] Other ranges available on request.
[2] Calibrated accuracy of the pressure sensor.
[3] Other sizes available on request.

GEOKON

The World Leader in Vibrating Wire Technology™

Geokon, Incorporated
48 Spencer Street
Lebanon, NH 03766
USA

1 • 603 • 448 • 1562
1 • 603 • 448 • 3216
geokon@geokon.com
www.geokon.com

Geokon maintains an ongoing policy of design review and reserves the right to amend products and specifications without notice.

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GEOKON

The World Leader in Vibrating Wire Technology

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E-mail: geokon@geokon.com
http://www.geokon.com

Instruction Manual

Models 4800, 4810, 4815, 4820 and 4830 VW Earth Pressure Cells

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(Doc Rev (M, 9/11)

Warranty Statement

Geokon, Inc. warrants its products to be free of defects in materials and workmanship, under normal use and service for a period of 13 months from date of purchase. If the unit should malfunction, it must be returned to the factory for evaluation, freight prepaid. Upon examination by Geokon, if the unit is found to be defective, it will be repaired or replaced at no charge. However, the WARRANTY is VOID if the unit shows evidence of having been tampered with or shows evidence of being damaged as a result of excessive corrosion or current, heat, moisture or vibration, improper specification, misapplication, misuse or other operating conditions outside of Geokon's control. Components which wear or which are damaged by misuse are not warranted. This includes fuses and batteries.

Geokon manufactures scientific instruments whose misuse is potentially dangerous. The instruments are intended to be installed and used only by qualified personnel. There are no warranties except as stated herein. There are no other warranties, expressed or implied, including but not limited to the implied warranties of merchantability and of fitness for a particular purpose. Geokon, Inc. is not responsible for any damages or losses caused to other equipment, whether direct, indirect, incidental, special or consequential which the purchaser may experience as a result of the installation or use of the product. The buyer's sole remedy for any breach of this agreement by Geokon, Inc. or any breach of any warranty by Geokon, Inc. shall not exceed the purchase price paid by the purchaser to Geokon, Inc. for the unit or units, or equipment directly affected by such breach. Under no circumstances will Geokon reimburse the claimant for loss incurred in removing and/or reinstalling equipment.

Every precaution for accuracy has been taken in the preparation of manuals and/or software, however, Geokon, Inc. neither assumes responsibility for any omissions or errors that may appear nor assumes liability for any damages or losses that result from the use of the products in accordance with the information contained in the manual or software.

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1. INTRODUCTION

1.1. Theory of Operation

Earth Pressure Cells, sometimes called Total Pressure Cells or Total Stress Cells are designed to measure stresses in soil or the pressure of soil on structures. Cells will respond not only to soil pressures but also to ground water pressures or to pore water pressure, hence the term total pressure or total stress. A simultaneous measurement of pore water pressure (μ), using a piezometer, is necessary to separate the effective stress (σ') from the total stress (σ) as defined by Terzaghi's principle of effective stress where;

$$\sigma' = \sigma - \mu$$

These parameters coupled with the soil strength characteristics will determine soil behavior under loads.

Earth pressure cells of the type described here are the hydraulic type; two flat plates are welded together at their periphery and are separated by a small gap filled with a hydraulic fluid. The earth pressure acts to squeeze the two plates together thus building up a pressure inside the fluid. If the plates are flexible enough, i.e. if they are thin enough relative to their lateral extent, then at the center of the plate the supporting effect of the welded periphery is negligible and it can be stated that at the center of the cell the external soil pressure is exactly balanced by the internal fluid pressure.

This is true only if the deflection of the plates is kept to a minimum and thus it is important that the cell be stiff. This in a practical sense means that the fluid inside the cell should be as incompressible as possible and that the pressure transducer required to measure the fluid pressure should also be stiff having very little volume change under increasing pressure.

Tests conducted by various researchers (as reported by Dunnicliff, 1988) have shown that the introduction of a flat stress cell into a soil mass will alter the stress field in a way dependent on the relative stiffness of the cell with respect to the soil and also with respect to the aspect ratio of the cell, i.e. the ratio of the width of the cell to its thickness. A thick cell will alter the stress more than a thin cell. Hence, for these reasons, a thin, stiff cell is best and studies have shown an aspect ration of at least 20 to 1 to be desirable.

Ideally, the cell ought to be as stiff (compressible) as the soil. But in practice this is difficult to achieve. If the cell is stiffer (less compressible) than the soil then it will over-register the soil pressure because of a zone of soil immediately around the cell which is "sheltered" by the cell so that it does not experience the full soil pressure. This can be represented schematically as shown in Figure 1.

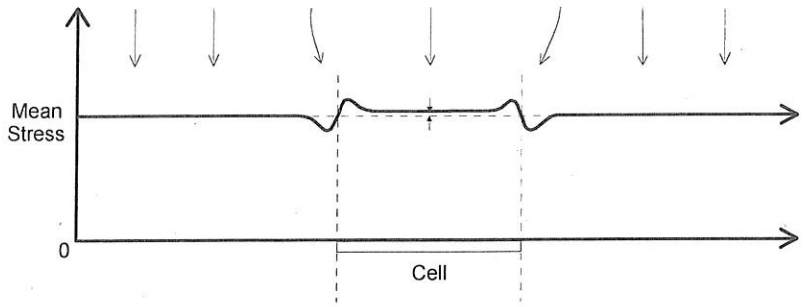

Figure 1 - Stress Redistribution, Weak Soil with Stiff Cell

As can be seen there is a stress concentration at the rigid rim but in the center of the cell the soil stress is only slightly higher than the mean soil stress, i.e. only slightly higher than the stress which would obtain were the cell not present.

In a stronger soil the de-stressed zone around the edge of the cell is more extensive and hence at the center of the cell the degree of *over-registration* of the mean stress is greater. This is represented schematically in Figure 2.

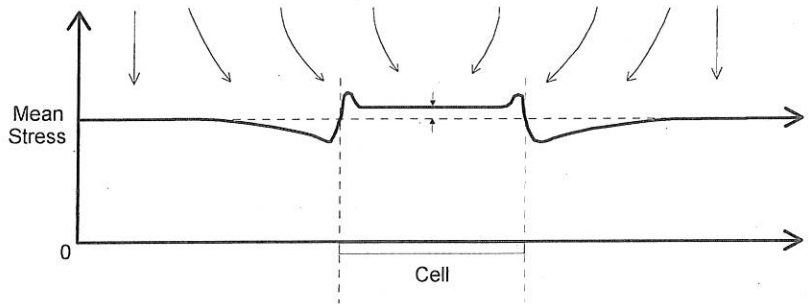

Figure 2 - Stress Redistribution, Strong Soil with Stiff Cell

In a stiff soil the cell may be less stiff (more compressible) than the soil, in which case the cell will *under-register* the mean soil stress as the stresses in the soil tend to "bridge" around the cell. This is represented schematically in Figure 3.

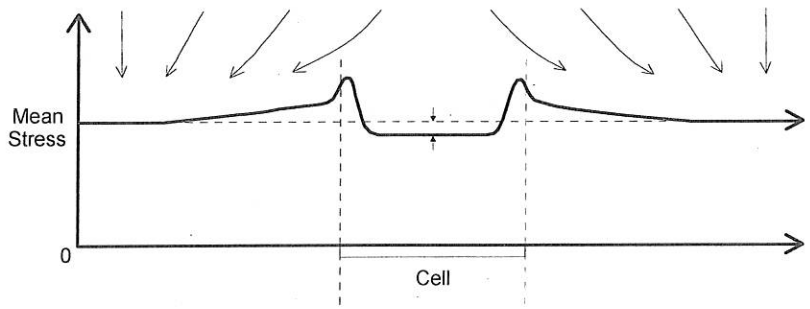

Figure 3 - Stress Redistribution, Stiff Soil with Weak Cell

Tests conducted at the University of Ohio (Ohio, USA) with several different soil types have shown that for Geokon cells the maximum degree of over or under-registration amounts to 15% of the mean soil stress.

Other factors should be kept in mind; the inherent variability of soil properties which give rise to varying soil stresses at different locations and a corresponding difficulty in getting a good sample of the mean stress from a limited number of cell locations. Also, the response of the cell to its immediate surroundings depends very largely on how closely the soil mass immediately around the cell has the same stiffness or compressibility or the same degree of compaction as the undisturbed soil mass. **Installation methods will need to pay particular attention to this detail.**

1.2. Earth Pressure Cell Design

Earth Pressure Cells are constructed from two stainless steel plates welded together around the periphery so as to leave a narrow space between them. This space is completely filled with de-aired hydraulic oil which is connected hydraulically to a pressure transducer where the oil pressure is converted to an electrical signal which is transmitted through a signal cable to the readout location.

In general Geokon Earth Pressure Cells use an all welded construction so that the space confining the oil is entirely metal not requiring 'O' rings which tend to trap air and reduce the cell stiffness. The oil is de-aired using a Nold DeAerator™ which materially improves the fluid stiffness and the performance of the cell. The pressure transducer normally employed is the Geokon Model 4500H which is available in several different pressure ranges (see Table A-1). The cable is attached to the transducer in a sealed, waterproof manner. For earth pressure cells located inside a soil mass the cable may be armored and provided with strain relief at the cell to reduce the likelihood of pull-out.

Located inside the vibrating wire pressure transducer housing is a thermistor for the measurement of temperature at the cell location. In addition, a tripolar plasma surge arrestor inside the transducer housing protects the vibrating wire pluck and read coils from electrical transients such as may be induced by direct or indirect lightning strikes.

Alternative pressure transducers with voltage (0-100 mV, 0-5 VDC, 0-10 VDC) or current (4-20 mA) output are also available for dynamic readout capability. Consult the factory for additional information.

1.3. Earth Pressure Cell Construction

Major components of the Model 4800 (rectangular and circular), 4810, 4815 and 4820 Earth Pressure Cells are shown in Figures 4 through 8.

The Model 4800 Earth Pressure Cells may be rectangular or circular in shape. The standard size for the rectangular Model 4800 is 150 mm × 250 mm (6" × 10"), for the circular it is 230 mm (9") in diameter. Standard thickness for both styles is 6 mm (aspect ratio ≈ 40). For laboratory tests smaller, thinner cells can be manufactured. Contact the factory for additional information.

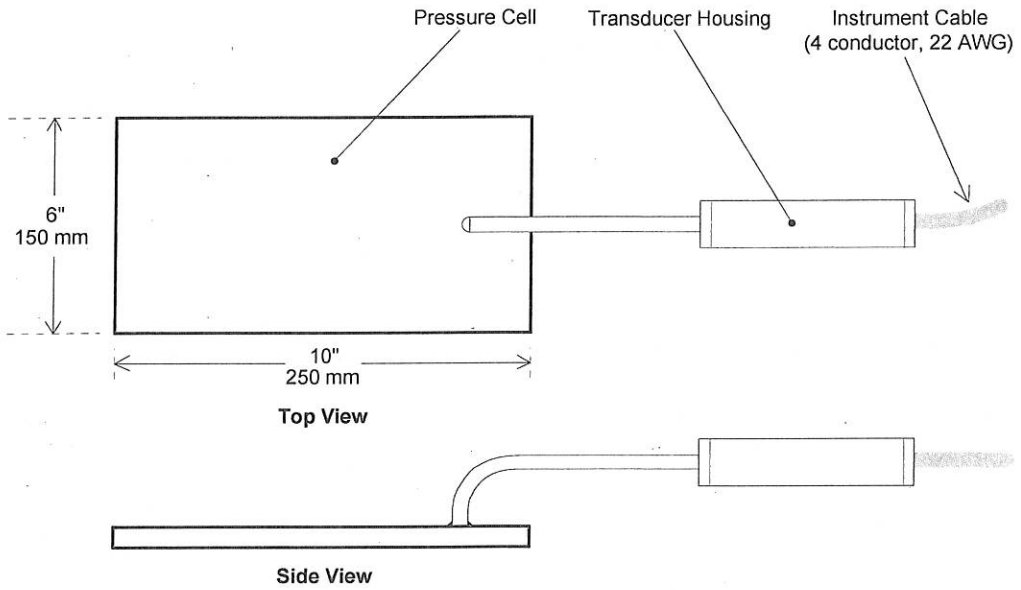

Figure 4 - Model 4800 Rectangular Earth Pressure Cell

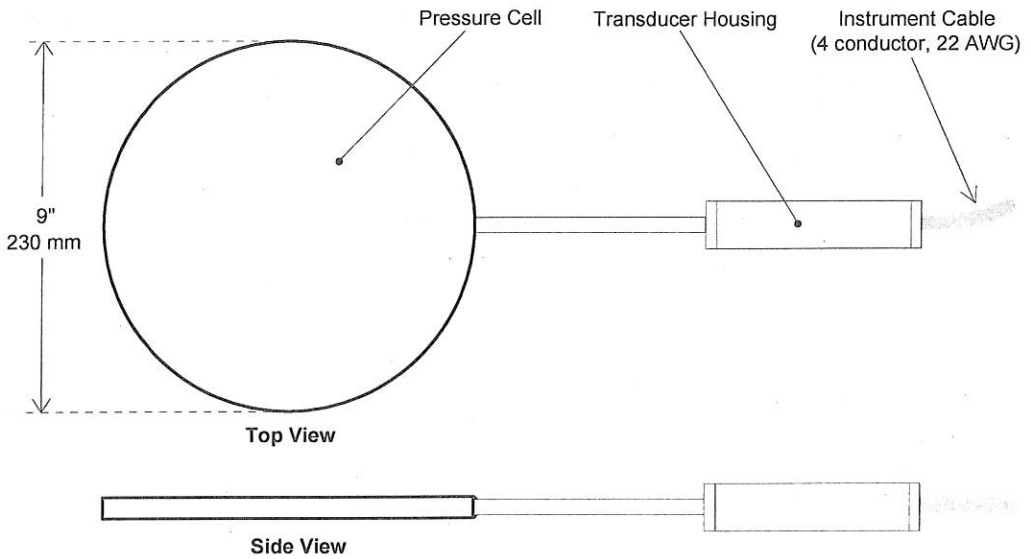

Figure 5 - Model 4800 Circular Earth Pressure Cell

The Model 4810 Earth Pressure Cell, or "contact" cell is designed for measuring soil pressures on structures. One of the plates is thick and designed to bear against the external surface of the structure in a way that will prevent flexure of the cell. The other plate is thin and reacts to the soil pressure.

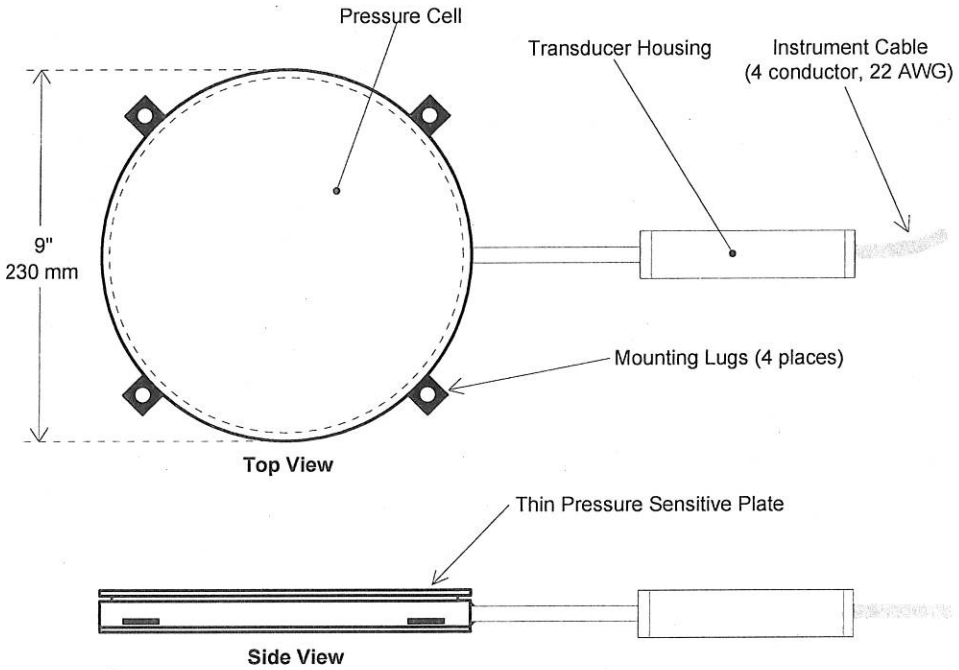

Figure 6 - Model 4810 Contact Pressure Cell

The Model 4815 Hydraulic Load Cell has been used for the measurement of loads in piles. And for the measurement of concentrated loads on tunnel linings. The pressure transducer housing is connected directly and perpendicular to the thick back plate

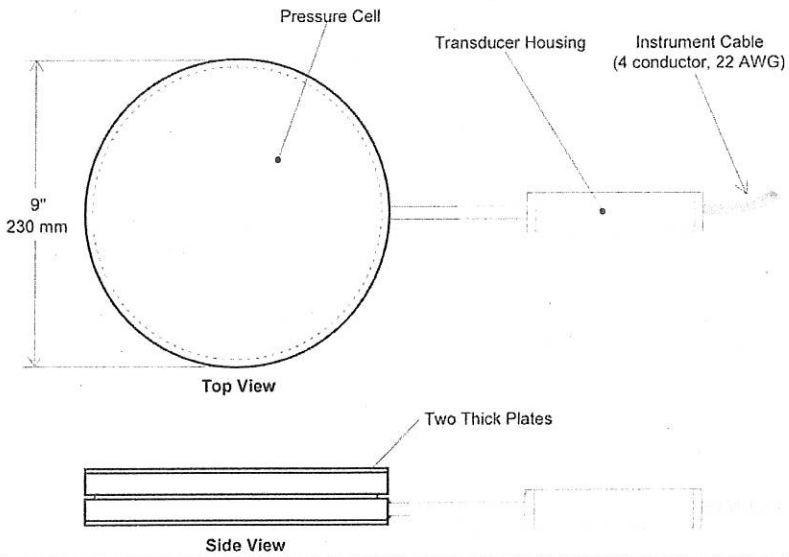

Figure 7 - Model 4815 Hydraulic Load Cell

The Model 4820 Earth Pressure Cell or "jack-out" cell is designed specifically for the measurement of soil pressures on the back side of slurry walls. The pressure transducer housing is connected directly and perpendicular to the thick back plate.

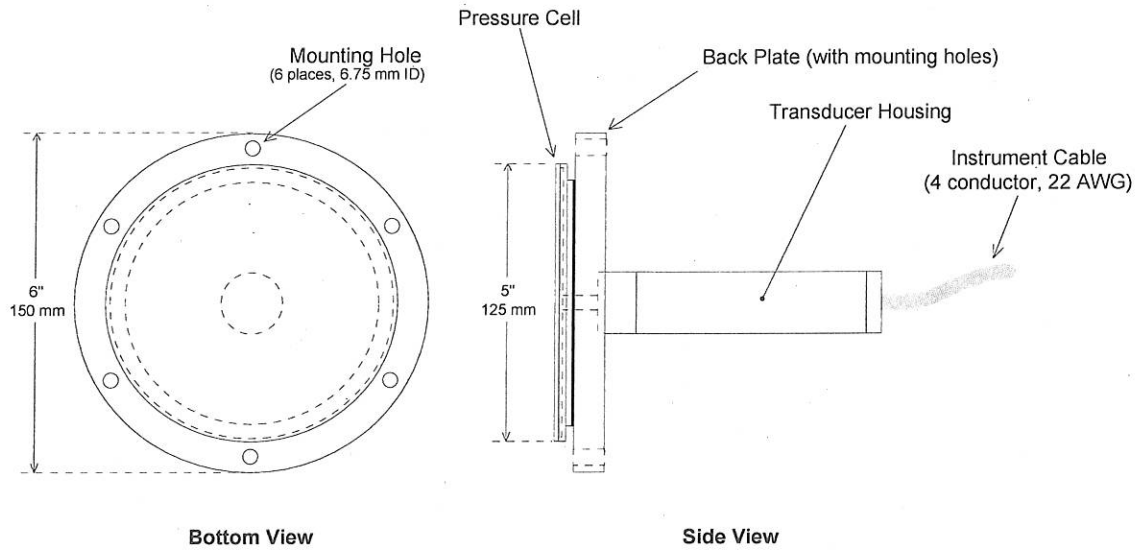

Figure 8 - Model 4820 Jack-Out Pressure Cell

2. INSTALLATION

2.1. Preliminary Tests

It is always wise, before installation commences, to check the cells for proper functioning. Each cell is supplied with a calibration sheet (Figure 13) which shows the relationship between readout digits and pressure and also shows the initial no load zero reading. The cell electrical leads (usually the red and black leads) are connected to a readout box (see section 3) and the zero reading given on the sheet is now compared to a current zero reading. The two readings should not differ by more than ≈50 digits after due regard to corrections made for different temperatures, barometric pressures and height above sea level and actual cell position (whether standing up or laying down).

By pressing on the cell it should be possible to change the readout digits, **causing them to fall as the pressure is increased.**

Checks of electrical continuity can also be made using an ohmmeter. Resistance between the gage leads should be approximately 180 ohms, ± 5%. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately 14.7Ω/1000' or 48.5Ω/km, multiply by 2 for both directions). Between the green and white should be approximately 3000 ohms at 25° (see Table B-1), and between any conductor and the shield should exceed 20 megohm.

2.2. Pressure Cell Installation

2.2.1. Installation of Model 4800 Earth Pressure Cells Inside Fills & Embankments

Earth pressure cells are normally installed with the flat surfaces horizontal to measure vertical stresses. However, they can be placed at other orientations, inside the fill, to measure stresses in other directions i.e. a cell placed with the flat surfaces vertical will measure horizontal stresses in a direction perpendicular to the plates of the cell. They are sometimes placed at angles of 45 degrees.

Experience has shown that attempts to measure earth pressures in fills frequently meets with failure. The problem is twofold: First, the stress distribution in the fill can be inherently variable due to varying properties of the ground and varying degrees of compaction of the ground. Thus the soil stress at one location may not be typical of the surrounding locations. Secondly, a cell installed directly in the fill could result in the creation of an anomolous zone immediately around the cell where there may be a different, more fine-grained material, under a lesser degree of compaction. (The material around the cell may be poorly compacted because of the need to avoid damage to the cell.)

In an earth fill, this zone of poor compaction would not be expected to be a problem since the earth above might be expected to simply move downwards to fill the voids and consolidate the ground. However, under the influence of rain water and vibration, any spaces in the soil immediately around the cell may grow so that the cell becomes completely de-coupled from the soil around it. In such a situation the internal soil stresses simply go around the cell instead of through it. The cell will then register only a very low pressure which does not change as the loads increase. This situation occurs frequently.

The best way to avoid the problem is to cast the cell inside a weak grout

A method used successfully in South Africa, by Oosthuizen et al, essentially uses the techniques similar to the one described in section 2.2.5. Installation of the cells begins when the fill has reached a height of 1 meter above the instrument level. The Instrument location and the cable trenches are excavated 1 meter deep, the instrument pocket, with 45° sloping sides, (See Figure 9)

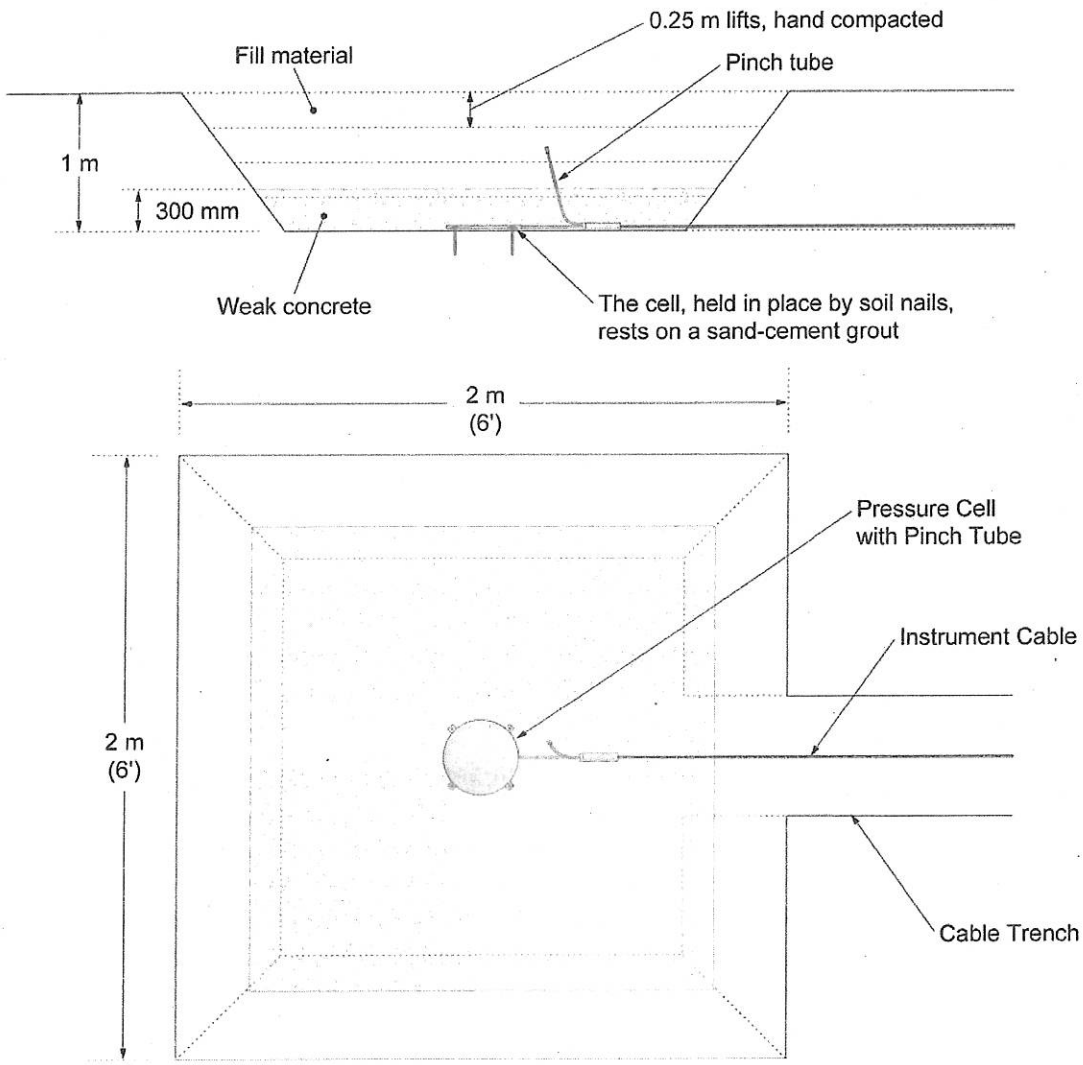

Figure 9 - Model 4800 Earth Pressure Cell Installation

The cells, (Model 4800 complete with pinch tubes and lugs), are positioned on a thin layer of non-shrink sand-cement grout and are nailed in position using the lugs on the cells provided for this purpose. The excavated pocket is then backfilled to a depth of 300mm with a weak concrete in 100mm

Application	**Grout for Medium to Hard Soils**		**Grout for Soft Soils**	
Materials	Weight	Ratio by Weight	Weight	Ratio by Weight
Water	30 gallons	2.5	75 gallons	6.6
Portland Cement	94 lbs (1 sack)	1	94 lbs (1 sack)	1
Bentonite	25 lbs (as required)	0.3	39 lbs (as required)	0.4
Notes	The 28 day compressive strength of this mix is about 50 psi, similar to very stiff to hard clay. The modulus is about 10,000 psi		The 28 day strength of this mix is about 4psi, similar to very soft clay.	

Table 1 showing Cement/bentonite/water ratios for two grout mixes.

layers, vibrated with a poker vibrator. After 24 hours the cells are pressurized, by pinching the pinch tubes until the pressure in the cell, displayed on a connected Readout Box, starts to change. The instrument location containing the grouted cells and the cable trench is then backfilled in 250mm layers, using the same material as the main fill placed by hand and compacted with pneumatic or gasoline backfill tampers, or vibratory trench rollers. After this, standard construction filling and compaction practices can continue.

Earth Pressure Cells clusters, placed according to the methods outlined above, may be installed either in trenches, below the temporary embankment grade, or in ramps above the temporary embankment grade. In dams, for example, it is usually convenient to install in trenches in the impervious rolled fill core, and in ramps in the filter zones and compacted rockfill shell zones. In earth embankments it is convenient to install in trenches. By so doing, adequate degrees of compaction of the backfill can be more easily obtained without damage to the cell clusters or cable arrays. As the cells are being covered and compacted, repeated readings should taken to ensure that the cells are continuing to function properly.

See section 2.3 for cable installation and protection.

2.2.2. Installation of Model 4810 Contact ("fat-back") Pressure Cell

This section details installation instructions for the Model 4810 Earth Pressure Cells which are used for the measurement of earth pressures on structures. In backfills for piers, piles, bridge abutments, retaining walls, culverts and other structures the cells may be installed either inside a concrete structure being poured or directly on the surface of an existing structure. For slurry walls the Model 4820 Earth Pressure Cell is used as described in Section 2.2.4.

Installation in Poured Concrete

When pouring concrete the cells can be held to the forms using nails and the lugs welded to the edge of the cell (see Figure 5). Position the cell so that the thin pressure sensitive plate is directly against the concrete form (see Figure 10). Nail the plates to the form lightly in such a manner that they engage the concrete sufficiently so that they do not pull out of the concrete when the forms are removed. Route the cable inside the concrete to a convenient readout location or to a blockout inside where excess cable can be coiled. Protect the cable from damage during concrete placement and vibration, by tying it to adjacent rebars.

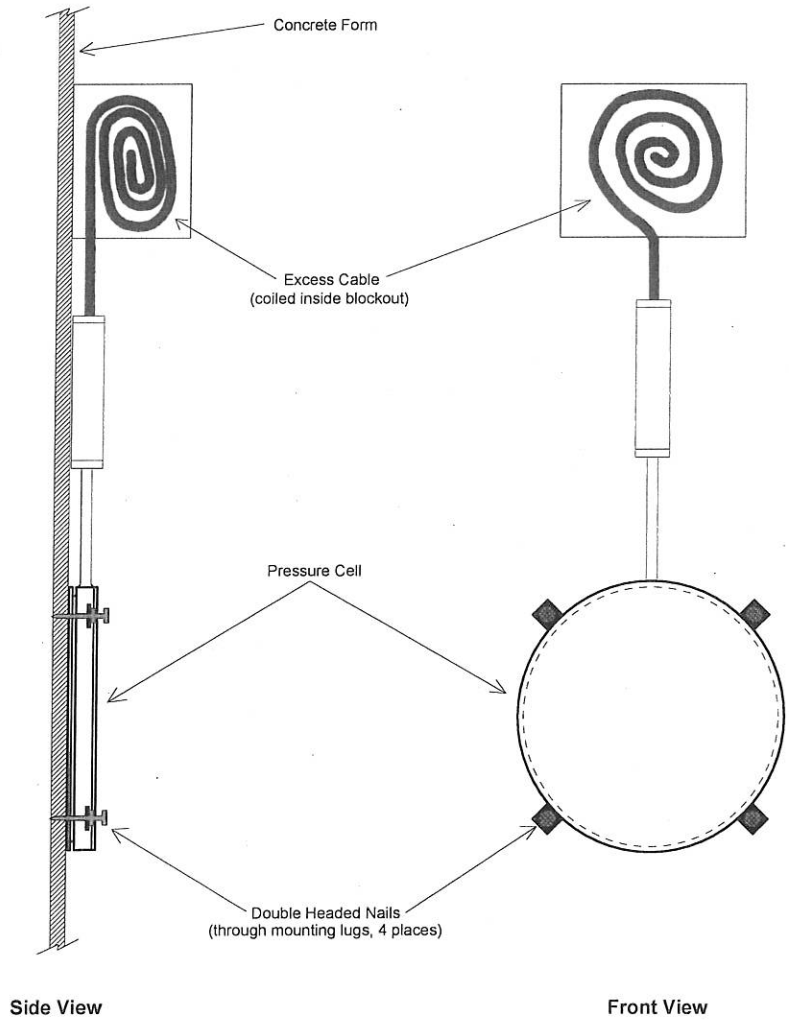

Figure 10 - Attachment of Model 4810 to Concrete Form

Installation on Existing Structures

Again the lugs welded to the edge of the cell can be used to hold the cell against the structure using nails, lag bolts, tie wire, etc. Even if the surface is smooth, but especially where the surface is rough or irregular a mortar pad between the cell and the structure is required. See Figure 11.

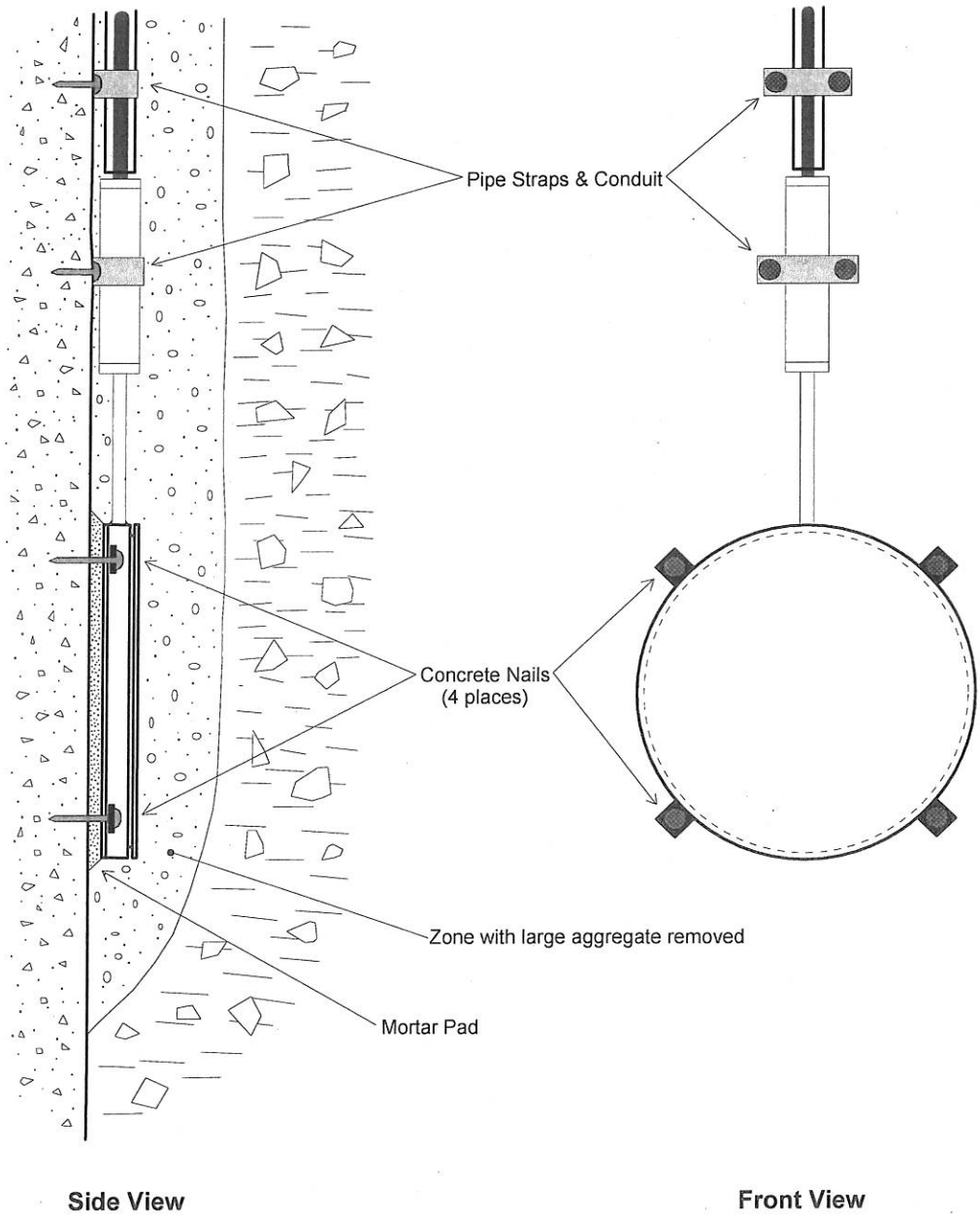

Figure 11 - Model 4810 Contact Pressure Cell Installation

Use the lugs on the cell as a template to locate the position for drilling holes for the installation of expanding anchors or install the anchors nearby and use wire to hold the cells in place. Alternately the cell may be nailed in place using the lugs as a guide. First mix up some quick setting cement mortar or epoxy cement. Trowel this onto the surface then push the cell into the cement so that the excess cement extrudes out of the edges of the cell. Hold the cell in place while the cement sets up, then complete the installation by adding the lag bolts (using the expansion anchors) and tightening or nailing the cell in place. Protect the cell, transducer housing and cable from direct contact with large chunks of rock by covering them with fine grained fill material from which all pieces larger than about 10 mm (0.5") have been removed. This fine material is kept next to the cell and cable as the fill is placed. Additional cable protection can be achieved by using metal conduit strapped to the surface of the structure.

2.2.3. Installation of Model 4815 Hydraulic Load Cell.

A particular installation, shown in figure 12, used the Model 4815 Hydraulic Load Cell to measure the concentrated load on a tunnel lining from an existing wooden pile (supporting a building above) that had been cut short by the tunnel excavation in frozen ground. The load cell was designed to measure any increase of load on the tunnel lining that might occur when, at the end of tunnel construction, the ground was allowed to thaw out. The load cell was positioned below the bottom of the pile and temporarily held in place with lugs and a mortar pad until the shotcrete tunnel lining was sprayed.

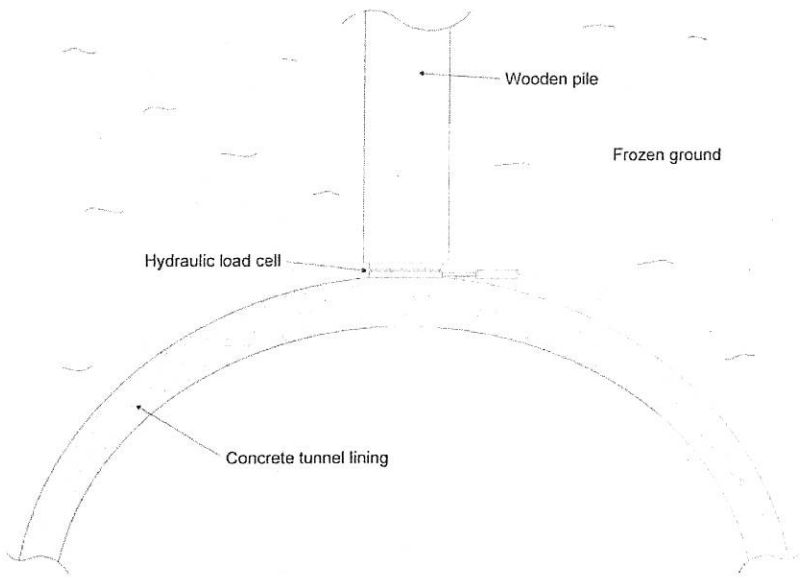

Figure 12 - Model 4815 Hydraulic Load Cell Measuring Loads on a Tunnel Lining

2.2.4. Installation of Model 4820 Jack-Out Pressure Cell in Slurry Trenches.

The Jack-Out Pressure first needs to be assembled into the jack-out frame. The assembly is shown in Figure 13. The support plate has a circular hole cut in it and bolt holes to fit the Jack-Out Pressure Cell (JOPC), and is connected to one end of a double-acting hydraulic jack by means of steel struts. The support plate and reaction plate are cambered top and bottom to prevent them from snagging on the sides of the slurry trench. The reaction plate is attached to the other side of the double-acting hydraulic jack. The jack is attached firmly to the rebar cable and arranged so that the plates are free to move outwards. The hydraulic line and signal cable are tied off to one of the rebars at intervals of 1 meter (3 feet).

When the rebar cage has been lowered to its proper depth, the jack is activated, forcing the two plates out against the trench walls.

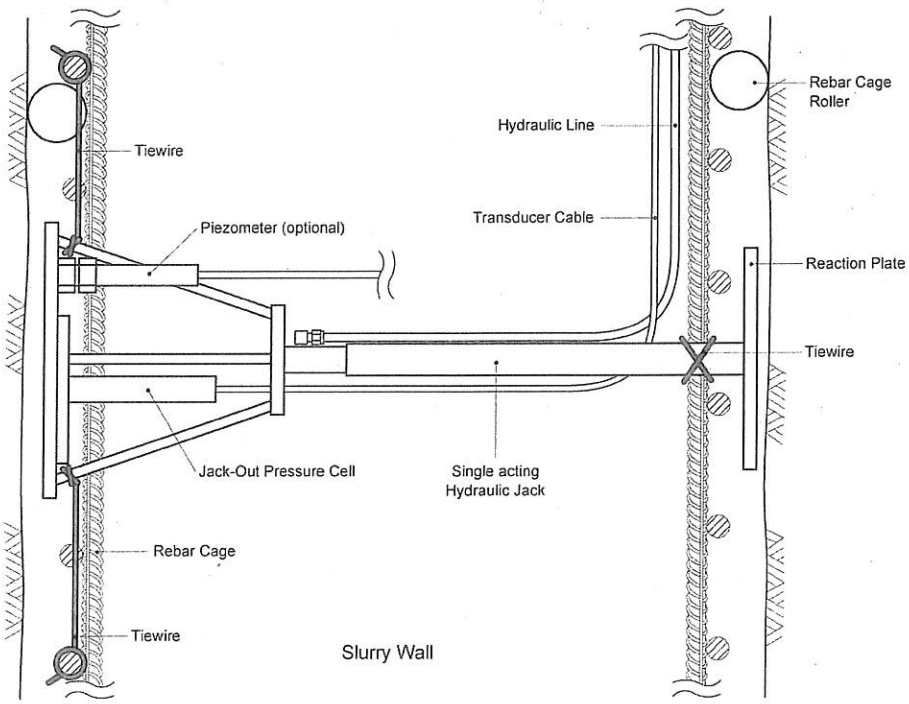

Figure 13 - Model 4820 Jack-Out Pressure Cell Installation

Observation of the pressure indicated by the JOPC (see section 3 for readout instructions) will indicate when the cell has made contact with the wall. Pump up the jack until the JOPC reading indicates a pressure roughly 70KPa (10psi) greater than the slurry pressure at JOPC depth. This ensures that the cell is bearing against the walls of the trench and that the concrete grout pressure will not close the jack and allow the reaction plates to move away from the trench walls. Check the JOPC reading from time to time because the pressure might bleed away if the walls of the trench are soft and yielding. Repressurise as needed. Leave the jack pressurised until the grout has set up.

2.2.5. Installation of Cells to Measure Earth Pressure at the Base of Footings, Floor Slabs, Pavements, Etc.

Experience has shown that attempts to measure contact earth pressures on the base of footings, floor slabs, pavements, etc., frequently meets with failure. The problem is twofold: First, the contact stress distribution can be inherently variable due to varying properties of the ground and varying degrees of compaction of the ground. Thus the contact stress at one location may not be typical of the surrounding locations. Secondly, a cell installed as described in section 2.2.1. could result in the creation of an anomolous zone immediately around the cell where there may be a different, more fine grained material, under a lesser degree of compaction. (The material around the cell may be poorly compacted because of the need to avoid damage to the cell.)

In an earth fill, this zone of poor compaction would not be a problem, since the earth above would simply move downwards to fill the voids and consolidate the ground. However, where there is a concrete slab immediately above the cell this consolidation may not take place and in fact, under the influence of rain water and vibration, the spaces around the cell may grow so that the cell becomes completely de-coupled from the concrete above. In such a situation the concrete slab bridges over the gap and the loads in the concrete simply go around the cell instead of through it. The cell registers only a very low pressure which does not change as the loads increase.

The best way to avoid the problem, if at all possible, is to cast the cell inside the concrete. This can often be done when the initial concrete bonding layer is spread over the surface of the ground. At this time a Model 4850-2 Concrete Stress Cell with a pinch tube, is pressed into the bonding layer so that it rests against the ground below. A weighted tripod can be used to hold the stress cell in place until the concrete hardens. The pinch tube is arranged to protrude above the bonding layer and, when the concrete has hardened, it is used to pressurize the cell and ensure good contact between the cell and the surrounding concrete. See Figure 12.

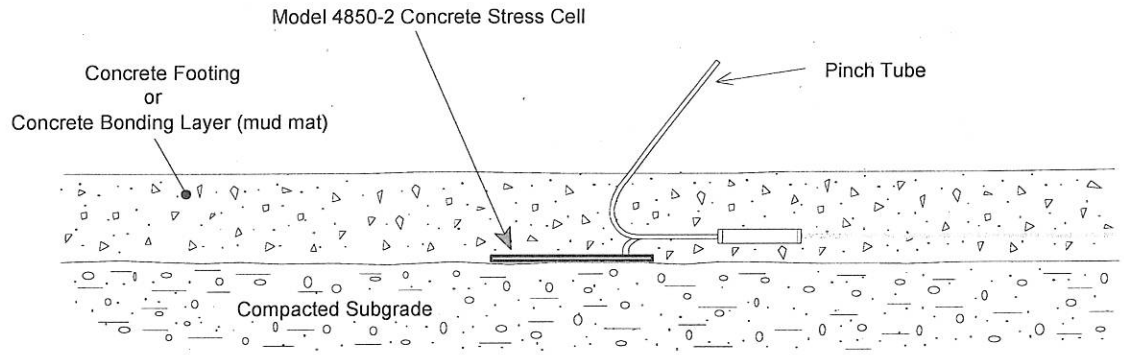

Figure 14 - Model 4850-2 Concrete Stress Cell Installation

The advantage of this method lies in its simplicity and in that it permits the ground below the concrete to be completely compacted in the normal way.

2.2.6. Installation of Push-in Pressure Cells to Measure lateral Earth Pressures.

The Model 4830 is designed to be pushed into soft soils using available drill rods, usually AW. Unless the ground is very soft it is recommended that a borehole be drilled to within about 2ft of the desired location and then push the cell the rest of the way.
A few things to note and be aware of:
1. **Temperature effects.**
This pressure cell is relatively stiff due to the geometry and the need for a robust construction for pushing into the ground. It is always advisable to obtain the pre-installation zero pressure readings in the borehole at the borehole temperature. It may take a significant amount of time for the sensor to come to thermal equilibrium but this is an important measurement and if it is not possible to take this reading in the borehole it may be possible to take the reading in a bucket of water that is at the ground temperature.
2. **Piezometer Saturation**
The piezometer filter and sensor are saturated at the factory and sealed with Mylar tape. Do not remove the tape until just before the sensor is installed in the ground. The filter is saturated by drawing a vacuum on the sensor and then allowing water to flow into the sensor when the vacuum is released. If the sensor is to be installed and then removed and reused at other sites the saturation process should be performed at each installation. Geokon can supply the necessary portable equipment to accomplish this.
3. **Overpressure**
When pushing the cell into the ground it is possible that pressures in excess of the sensors full scale range can be generated causing the sensor to experience a zero shift or even permanent damage. To prevent this, readings should be taken as the sensor is pushed. When the indicated pressure approaches 150% of full scale the pushing operation should be terminated until the sensor output comes back within its calibrated range.

2.3. Cable Installation

Cable placement procedures vary with individual installations. In general, however, all installations have in common the requirements that; 1) the cable must be protected from damage by angular particles of the material in which the cable is embedded, 2) the cable must be protected from damage by compaction equipment, 3) in earth and rock embankments and backfills, the cable must be protected from stretching as a result of differential compaction of the embankment, 4) in concrete structures, the cable must be protected from damage during placement and vibration of the concrete.

In embankments, cables may be embedded in a protective covering of sand or selected fine embankment materials. A typical installation might, for example, comprise the positioning of a series of cables on a prepared layer consisting of not less than 200 mm (8") of compacted selected fine material. In order to establish an acceptable grade without undue interference with construction operations, the prepared layer may be located either in a trench or on an exposed ramp. In rockfill dams with earthfill cores, for example, it is frequently convenient to install cable in trenches in the core and fine filter zones, and in ramps in the coarse filter and compacted rock fill shell zones. Individual cables should be spaced not less than 12 mm (0.5") apart, and no cable should be closer than 150 mm (6") to the edge of the prepared layer. In instances in which

cables must cross each other, or in which more than one layer of cables must be placed in a given array, the cables should be separated from each other by a vertical interval of not less than 50 mm (2") of hand-compacted sand or selected fine embankment material. Since the elongation capability of electrical cable is quite substantial, it is not necessary to place the cable with "S" shaped meanders, which in any case serve no purpose.

During the backfill of trenches in earth dams, a plug, approximately 0.5 meter (2 feet) in width, made of a mixture of 5% bentonite (by volume) from an approved source and exhibiting a free swell factor of approximately 600%, and 95% embankment material, can be placed in the trenches at intervals of not greater than 20 meters (50 feet). The purpose of the bentonite plugs is to reduce the possibility of water seepage through the embankment core along the back filled trenches.

The cable may be marked by using a mylar cable labels. For an individual cable the identification number should be taped near the end of the cable. Additional cable labels might be specified at regular intervals along the cable to aid in identification if cables need to dug up for splicing, etc.

Cables may be spliced, without affecting gage readings, nevertheless splicing should be avoided wherever possible. If necessary, waterproof the splice completely, preferably using an epoxy based splice kit such the 3M Scotchcast™, model 82-A1. These kits are available from the factory.

2.4. Electrical Noise

Care should be exercised when installing instrument cables to keep them as far away as possible from sources of electrical interference such as power lines, generators, motors, transformers, arc welders, etc. Cables should never be buried or run with AC power lines. The instrument cables will pick up the 50 or 60 Hz (or other frequency) noise from the power cable and this will likely cause a problem obtaining a stable reading. Contact the factory concerning filtering options available for use with the Geokon dataloggers and readouts should difficulties arise.

2.5. Initial Readings

Initial readings must be taken and carefully recorded along with the barometric pressure and temperature at the time of installation. Take the initial readings while the cell is in position, just prior to it being covered by fill and pouring of concrete. ***Again, it is imperative that initial readings at zero load are taken!***

3. TAKING READINGS

3.1 Operation of the GK-403 Readout Box

The GK-403 can store gage readings and also apply calibration factors to convert readings to engineering units. Consult the GK-403 Instruction Manual for additional information on Mode "G" of the Readout. The following instructions will explain taking gage measurements using Mode "B".

Connect the Readout using the flying leads or in the case of a terminal station, with a connector. The red and black clips are for the vibrating wire gage, the white and green clips are for the thermistor and the blue for the shield drain wire.

1. Turn on the Readout. Turn the display selector to position "B". Readout is in digits (see Equation 1).

2. Turn the unit on and a reading will appear in the front display window. The last digit may change one or two digits while reading. Press the "Store" button to record the value displayed. If the no reading displays or the reading is unstable see section 5 for troubleshooting suggestions. The thermistor will be read and output directly in degrees centigrade.

3. The unit will automatically turn itself off after approximately 2 minutes to conserve power.

3.2 Operation of the GK-404 Readout Box

The GK-404 is a palm sized readout box which displays the Vibrating wire value and the temperature in degrees centigrade.
The GK-404 Vibrating Wire Readout arrives with a patch cord for connecting to the vibrating wire gages. One end will consist of a 5-pin plug for connecting to the respective socket on the bottom of the GK-404 enclosure. The other end will consist of 5 leads terminated with alligator clips. Note the colors of the alligator clips are red, black, green, white and blue. The colors represent the positive vibrating wire gage lead (red), negative vibrating wire gage lead (black), positive thermistor lead (green), negative thermistor lead (white) and transducer cable drain wire (blue). The clips should be connected to their respectively colored leads from the vibrating wire gage cable.

Use the **POS** (Position) button to select position **B** and the MODE button to select **Dg** (digits). Other functions can be selected as described in the GK404 Manual.

The GK-404 will continue to take measurements and display the readings until the OFF button is pushed, or if enabled, when the automatic Power-Off timer shuts the GK-404 off.

The GK-404 continuously monitors the status of the (2) 1.5V AA cells, and when their combined voltage drops to 2V, the message **Batteries Low** is displayed on the screen. A fresh set of 1.5V AA batteries should be installed at this point

3.3. Measuring Temperatures

Each Vibrating Wire Pressure Cell is equipped with a thermistor for reading temperature. The thermistor gives a varying resistance output as the temperature changes. Usually the white and green leads are connected to the internal thermistor. The GK-401 Readout Box does not read temperatures – a digital ohmmeter is required.

1. Connect the ohmmeter to the two thermistor leads coming from the stress cell. (Since the resistance changes with temperature are so large, the effect of cable resistance is usually insignificant.)

2. Look up the temperature for the measured resistance in Table B-1 (Appendix B). Alternately the temperature could be calculated using Equation B-1 (Appendix B). For example, a resistance of 3400 ohms equivalent to 22° C. When long cables are used the cable resistance may need to be taken into account. Standard 22 AWG stranded copper lead cable is approximately 14.7Ω/1000' or 48.5Ω/km, multiply by 2 for both directions.

Note: The GK-403 and GK-404 readout boxes will read the thermistor and display temperature in °C automatically.

4. DATA REDUCTION

4.1. Pressure Calculation

The basic units utilized by Geokon for measurement and reduction of data from Vibrating Wire Earth Pressure Cells are "digits". The GK-401, GK-402 and GK-403 Readouts all display "digits" in the Earth Pressure Cell reading position. Calculation of digits is based on the following equation;

$$\text{Digits} = \left(\frac{1}{\text{Period(seconds)}}\right)^2 \times 10^{-3} \quad \text{or} \quad \text{Digits} = \frac{\text{Hz}^2}{1000}$$

Equation 1 - Digits Calculation

To convert digits to pressure the following equation applies;

Pressure = (Current Reading - Initial Reading) × Calibration Factor

or

$$\mathbf{P = (R_1 - R_0) \times G}$$

Equation 2 - Convert Digits to Pressure

The Initial Reading (R_0) is normally obtained during installation (usually the zero reading). The Calibration Factor (G, usually in terms of psi or kPa per digit) comes from the supplied Calibration Sheet (a **typical** calibration sheet is shown in Figure 15, page 21). To convert the output to other engineering units, multiply the Calibration Factor by the conversion multiplier listed in Table 1.

From → To ↓	psi	"H_2O	'H_2O	mm H_20	m H_20	"HG	mm HG	atm	mbar	bar	kPa	MPa
psi	1	.036127	.43275	.0014223	1.4223	.49116	.019337	14.696	.014503	14.5039	.14503	145.03
"H_2O	27.730	1	12	.039372	39.372	13.596	.53525	406.78	.40147	401.47	4.0147	4016.1
'H_2O	2.3108	.08333	1	.003281	3.281	1.133	.044604	33.8983	.033456	33.4558	.3346	334.6
mm H_20	704.32	25.399	304.788	1	1000	345.32	13.595	10332	10.197	10197	101.97	101970
m H_20	.70432	.025399	.304788	.001	1	.34532	.013595	10.332	.010197	10.197	.10197	101.97
"HG	2.036	.073552	.882624	.0028959	2.8959	1	.03937	29.920	.029529	29.529	.2953	295.3
mm HG	51.706	1.8683	22.4196	.073558	73.558	25.4	1	760	.75008	750.08	7.5008	7500.8
atm	.06805	.0024583	.0294996	.0000968	.0968	.03342	.0013158	1	.0009869	.98692	.009869	9.869
mbar	68.947	2.4908	29.8896	.098068	98.068	33.863	1.3332	1013.2	1	1000	10	10000
bar	.068947	.0024908	.0298896	.0000981	.098068	.033863	.001333	1.0132	.001	1	.01	10
kPa	6.8947	.24908	2.98896	.0098068	9.8068	3.3863	.13332	101.320	.1	100	1	1000
MPa	.006895	.000249	.002988	.00000981	.009807	.003386	.000133	.101320	.0001	.1	.001	1

Table 1 - Engineering Units Multiplication Factors

For example, assume an initial reading of $R_0 = 9101$, a present reading of, $R_1 = 7390$ and a Calibration Factor of -0.1192 kPa/digit. The calculated pressure is;

$$\mathbf{204\ kPa = (7390 - 9101) \times -0.1192}$$

[Appendix D shows how a second order poynomial can be used to improve accuracy]

4.2. Temperature Correction

The vibrating wire earth pressue cell is quite sensitive to temperature fluctuations but often temperature changes in the ground are minor and can be ignored. Corrections for temperature effects on the transducer alone can be made using the Thermal Factor (K) supplied on the calibration sheet (see Figure 13) along with an equation for its proper use. See Equation 3.

Temperature Correction = (Current Temperature - Initial Temperature) × Thermal Factor

or

$$\mathbf{P_{corrected} = (R_0 - R_1)G + (T_1 - T_0)K}$$

Equation 3 - Temperature Correction for the Transducer Only.

The Temperature Correction value is then added to the pressure calculated using Equation 2. For example, assume an initial temperature of 25° C, a temperature at the time of measurement of 12° C and a Thermal Factor of +0.03852 kPa/° C. The thermally corrected pressure is;

$$\mathbf{203.5\ kPa = 204 + (12 - 25) \times 0.03852}$$

Note that this correction for temperature applies only to the pressure transducer itself and not to the entire cell surrounded by soil or soil and concrete each with its own (different) temperature coefficient of expansion. Commercially it is not practical to measure this effect without incurring huge expenses. Suffice to say that the effect is usually small at depths where the temperature is fairly constant. But where temperatures do vary the effect can be quite large. For more information see Appendix D which gives a theoretical treatment.
In practise the best way to compensate for temperatures is to derive a factor from simultaneous measurements of pressure and temperature at times when the temperature is changing and when it can be safely assumed that the applied load is not changing.

4.3. Barometric Correction

The pressure transducer used in Geokon Vibrating Wire Earth Pressure Cells is evacuated and hermetically sealed and will respond to barometric pressure fluctuation. If a correction for these fluctuations is required then it is necessary to record the initial barometric pressure, S_0, and the barometric pressure at the time of each reading, S_1, and subtract the change (S_1 -S_0) from the calculated pressure reading.

5. TROUBLESHOOTING

Maintenance and troubleshooting of Vibrating Wire Pressure Cells is confined to periodic checks of cable connections. Once installed, the cells are usually inaccessible and remedial action is limited. Consult the following list of problems and possible solutions should difficulties arise. Consult the factory for additional troubleshooting help.

Symptom: Pressure Cell Readings are Unstable

- ✓ Is the readout box position set correctly? If using a datalogger to record readings automatically are the swept frequency excitation settings correct? Try reading the cell on a different readout position. For instance, channel A of the GK-401 and GK-403 might be able to read the pressure cells. To convert the Channel A period display to digits use Equation 1.
- ✓ Is there a source of electrical noise nearby? Most probable sources of electrical noise are motors, generators, transformers, arc welders and antennas. Make sure the shield drain wire is connected to ground whether using a portable readout or datalogger. If using the GK-401 Readout connect the clip with the green boot to the bare shield drain wire of the pressure cell cable. If using the GK-403 connect the clip with the blue boot to the shield drain wire.
- ✓ Does the readout work with another pressure cell? If not, the readout may have a low battery or be malfunctioning. Consult the appropriate readout manual for charging or troubleshooting directions.

Symptom: Pressure Cell Fails to Read

- ✓ Is the cable cut or crushed? This can be checked with an ohmmeter. Nominal resistance between the two gage leads (usually red and black leads) is 180Ω, +/- 5%. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately 14.7Ω /1000' or 48.5Ω/km, multiply by 2 for both directions). If the resistance reads infinite, or

very high (megohms), a cut wire must be suspected. If the resistance reads very low (<100 Ω) a short in the cable is likely.

✓ Does the readout or datalogger work with another pressure cell? If not, the readout or datalogger may be malfunctioning. Consult the readout or datalogger manual for further direction.

GEOKON 48 Spencer St. Lebanon, NH 03766 USA

Vibrating Wire Pressure Transducer Calibration Report

Model Number: 4500INS-350 kPa

Date of Calibration: September 20, 2011

Serial Number: 1124847

Temperature: 22.6 °C

Barometric Pressure: 999.1 mbar

Technician: Stuart Kemp

Applied Pressure (kPa)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Pressure (Linear)	Error Linear (%FS)	Calculated Pressure (Polynomial)	Error Polynomial (%FS)
0.0	8980	8981	8981	0.298	0.09	-0.059	-0.02
70.0	8395	8395	8395	70.06	0.02	70.13	0.04
140.0	7811	7811	7811	139.7	-0.10	139.9	-0.02
210.0	7223	7223	7223	209.7	-0.08	210.0	0.00
280.0	6634	6634	6634	279.9	-0.03	280.0	-0.01
350.0	6042	6043	6043	350.4	0.11	350.0	0.01

(kPa) Linear Gage Factor (G): -0.1192 (kPa/ digit)

Regression Zero: 8983

Polynomial Gage factors: A: -3.082E-07 B: -0.1145 C: _____

Thermal Factor (K): 0.03852 (kPa/ °C)

Calculate C by setting P=0 and R_1 = initial field zero reading into the polynomial equation

(psi) Linear Gage Factor (G): -0.01728 (psi/ digit)

Polynomial Gage Factors: A: -4.47E-08 B: -0.01661 C: _____

Thermal Factor (K): 0.005586 (psi/ °C)

Calculate C by setting P=0 and R_1 = initial field zero reading into the polynomial equation

Calculated Pressures:

Linear, $P = G(R_1 - R_0) + K(T_1 - T_0) - (S_1 - S_0)^*$

Polynomial, $P = AR_1^2 + BR_1 + C + K(T_1 - T_0) - (S_1 - S_0)^*$

*Barometric pressures expressed in kPa or psi. Barometric compensation is not required with vented transducers.

The above instrument was found to be in tolerance in all operating ranges.
The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

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Figure 15 - Sample Model 4800 Calibration Sheet

APPENDIX A - SPECIFICATIONS

A.1. Earth Pressure Cells

Model:	4800 Earth Pressure Cell (rectangular)	4800 Earth Pressure Cell (circular)	4810 Contact Pressure Cell	4820 Jack-Out Pressure Cell
Ranges:[1]	70kPa (10psi) 170kPa (25psi) 350 kPa (50 psi) 700 kPa (100 psi) 1MPa (150 psi) 2Mpa (300psi) 3 MPa (435 psi) 5 MPa (750 psi) 7.5 MPa (1100 psi) 20 MPa (3000 psi)	70kPa (10psi) 170kPa (25psi) 350 kPa (50 psi) 700 kPa (100 psi) 1MPa (150 psi) 2Mpa (300psi) 3 MPa (435 psi) 5 MPa (750 psi) 7.5 MPa (1100 psi) 20 MPa (3000 psi))	350kPa (50psi) 700kPa (100psi) 1Mpa (150psi) 2 MPa (300 psi) 3 MPa (500 psi) 5 MPa (750 psi)	350kPa (50psi) 700kPa (100psi) 1Mpa (150psi) 2 MPa (300 psi) 3 MPa (500 psi) 5 MPa (750 psi)
Resolution:	±0.025% FSR			
Accuracy:	±0.5% FSR (±0.1% FSR with a polynomial expression)			
Linearity:	±0.5% FSR (standard) ±0.1% FSR (optional)			
Overrange:	150% FSR			
Operating Temperature:	-20 to +80° C			
Excitation Frequency Range Output Frequency Range	1400-3500Hz 2000-3000Hz			
Cell Dimensions:[2] (active area)	100 × 200 mm 4 × 8"	230 mm OD 9" OD	230 mm OD 9" OD	125 mm OD 5" OD
Coil Resistance:	150 Ω			
Cell Material:	304 Stainless Steel			
Transducer Material:	303 & 304 Stainless Steel			
Weight:	2.3 kg. 5 lbs.	2.3 kg. 5 lbs.	4.7 kg. 10.3 lbs.	2.7 kg. 6 lbs.
Electrical Cable:[3]	2 twisted pair (4 stranded conductor), 22 AWG Foil shield (with drain wire), PVC jacket, nominal OD=6.3 mm (0.250")			

Table A-1 Earth Pressure Cell Specifications

Notes:
[1] Consult the factory for other ranges available.
[2] Consult the factory for other sizes available.
[3] Consult the factory for alternate cable types.

A.2. Thermistor (see Appendix B also)

Range: -80 to +150° C
Accuracy: ±0.5° C

APPENDIX B - THERMISTOR TEMPERATURE DERIVATION

Thermistor Type: YSI 44005, Dale #1C3001-B3, Alpha #13A3001-B3

Resistance to Temperature Equation:

$$T = \frac{1}{A + B(LnR) + C(LnR)^3} - 273.2$$

Equation B-1 Convert Thermistor Resistance to Temperature

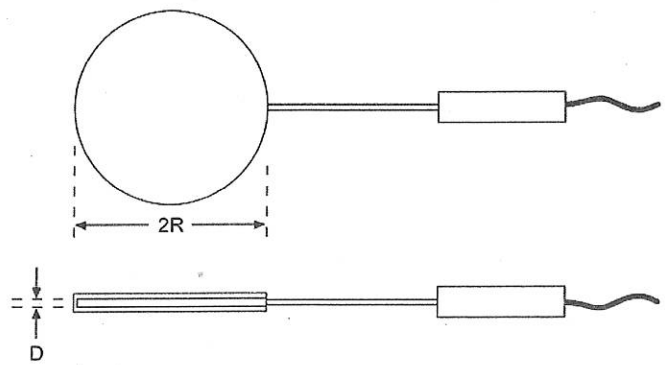
where: T = Temperature in °C.
LnR = Natural Log of Thermistor Resistance
$A = 1.4051 \times 10^{-3}$ (coefficients calculated over the –50 to +150° C. span)
$B = 2.369 \times 10^{-4}$
$C = 1.019 \times 10^{-7}$

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
201.1K	-50	16.60K	-10	2417	+30	525.4	+70	153.2	+110
187.3K	-49	15.72K	-9	2317	31	507.8	71	149.0	111
174.5K	-48	14.90K	-8	2221	32	490.9	72	145.0	112
162.7K	-47	14.12K	-7	2130	33	474.7	73	141.1	113
151.7K	-46	13.39K	-6	2042	34	459.0	74	137.2	114
141.6K	-45	12.70K	-5	1959	35	444.0	75	133.6	115
132.2K	-44	12.05K	-4	1880	36	429.5	76	130.0	116
123.5K	-43	11.44K	-3	1805	37	415.6	77	126.5	117
115.4K	-42	10.86K	-2	1733	38	402.2	78	123.2	118
107.9K	-41	10.31K	-1	1664	39	389.3	79	119.9	119
101.0K	-40	9796	0	1598	40	376.9	80	116.8	120
94.48K	-39	9310	+1	1535	41	364.9	81	113.8	121
88.46K	-38	8851	2	1475	42	353.4	82	110.8	122
82.87K	-37	8417	3	1418	43	342.2	83	107.9	123
77.66K	-36	8006	4	1363	44	331.5	84	105.2	124
72.81K	-35	7618	5	1310	45	321.2	85	102.5	125
68.30K	-34	7252	6	1260	46	311.3	86	99.9	126
64.09K	-33	6905	7	1212	47	301.7	87	97.3	127
60.17K	-32	6576	8	1167	48	292.4	88	94.9	128
56.51K	-31	6265	9	1123	49	283.5	89	92.5	129
53.10K	-30	5971	10	1081	50	274.9	90	90.2	130
49.91K	-29	5692	11	1040	51	266.6	91	87.9	131
46.94K	-28	5427	12	1002	52	258.6	92	85.7	132
44.16K	-27	5177	13	965.0	53	250.9	93	83.6	133
41.56K	-26	4939	14	929.6	54	243.4	94	81.6	134
39.13K	-25	4714	15	895.8	55	236.2	95	79.6	135
36.86K	-24	4500	16	863.3	56	229.3	96	77.6	136
34.73K	-23	4297	17	832.2	57	222.6	97	75.8	137
32.74K	-22	4105	18	802.3	58	216.1	98	73.9	138
30.87K	-21	3922	19	773.7	59	209.8	99	72.2	139
29.13K	-20	3748	20	746.3	60	203.8	100	70.4	140
27.49K	-19	3583	21	719.9	61	197.9	101	68.8	141
25.95K	-18	3426	22	694.7	62	192.2	102	67.1	142
24.51K	-17	3277	23	670.4	63	186.8	103	65.5	143
23.16K	-16	3135	24	647.1	64	181.5	104	64.0	144
21.89K	-15	**3000**	**25**	624.7	65	176.4	105	62.5	145
20.70K	-14	2872	26	603.3	66	171.4	106	61.1	146
19.58K	-13	2750	27	582.6	67	166.7	107	59.6	147
18.52K	-12	2633	28	562.8	68	162.0	108	58.3	148
17.53K	-11	2523	29	543.7	69	157.6	109	56.8	149
								55.6	150

Table B-1 Thermistor Resistance versus Temperature

APPENDIX C. Temperature Effect on Earth Pressure and Concrete Stress Cells – Some Theoretical Considerations

The following theoretical treatment is by no means rigorous - there are some questionable assumptions and approximations – but it should give some idea of the magnitude of the thermal effect to be expected on hydraulic earth pressure cells, buried in soil, or installed at the contact between soil and structure, and on concrete stress cells embedded in concrete.



Consider a circular cell of radius R containing a liquid film of thickness D, coefficient of thermal expansion Kppm/°C, and bulk modulus G.

For a temperature rise of 1° C the expansion, Y_T of the liquid film is given by the equation:

$$Y_T = KD \quad \text{.....} \quad ①$$

Expansion of the liquid is resisted by the confinement of the surrounding medium (soil or concrete) and this causes a pressure rise, P, in the liquid and a compression of the liquid, Y_c, given by the equation:

$$Y_c = PD/G \quad \text{.....} \quad ②$$

So that the net expansion, Y, of the cell is equal to:

$$Y = D\,(K - P/G) \quad \text{.....} \quad ③$$

Liquid pressure inside the cell causes deformation of the surrounding medium. The amount of deformation can be quantified by modification of formulas found in [1], where the deformation, Y, produced by a uniform pressure, P, acting on a circular area, R radius, on the surface of a material with modulus of elasticity, E, and Poissons ratio, ν, is given by:

$$Y = \frac{2\,PR\,(1-\nu^2)}{E} \qquad \text{at the center}$$

And

$$Y = \frac{4\,PR\,(1-\nu^2)}{\pi\,E} \qquad \text{at the edge}$$

And the difference is $\underline{PR(1-v^2)}(2-4/\pi)/E$

The above formulas apply to pressures acting on a free surface. However, in the confined case, Y, at the edge of the cell, can be assumed to be nearly zero and so Y, at the center, is assumed to be:

$$\frac{PR(1-v^2)}{E}(2-4/\pi) \quad \text{i.e. the same difference as before.}$$

If the average Y, across the cell is assumed to be half this value and if the deformation of the medium on either side of the cell is assumed to be the same then the average total expansion of the cell is given by:

$$Y = 0.73\ PR(1-v^2) \times 0.5 \times 2/E = 0.73\ PR(1-v^2)/E \quad \text{.....} \ ④$$

Equating ③ & ④ gives:

$$P(D/G + 0.73\ R(1-v^2)/E) = KD \quad \text{.....} \ ⑤$$

If one side of the cell lies in contact with a rigid structure, e.g. a concrete retaining wall or a concrete bridge footing, then

$$Y = 0.73\ \underline{PR(1-v^2)} \times 0.5/E \quad = 0.36\ \underline{PR(1-v^2)/E} \quad \text{.....} ⑥$$

And $$P(D/G + 0.36\ R(1-v^2)/E) = KD \quad \text{.....} ⑦$$

Where E pertains to the soil material.

Since these expressions are only approximate they can be simplified even further: for all $E < 10 \times 10^6$ psi the term D/G is negligible so long as the cell is designed and constructed properly, i.e., G is large, (no air trapped inside the cell), and D is small. Also, the term $(1-v^2)$ can be replaced by 0.91 since v usually lies between 0.25 and 0.35.
Hence, for total embedment:

$$P = 1.5\ EKD/R \quad \text{psi} / {}^{\circ}\text{C}$$

And, for contact pressure cells:

$$P = 3\ EKD/R \quad \text{psi} / {}^{\circ}\text{C}$$

Some typical values of the various parameters are:

Liquid	$K \times 10^{-6}$ / °C	$G \times 10^{6}$ psi
Oil	700	0.3
Mercury	180	3.6
Water	170	0.3
Glycol	650	
50/50 Glycol/Water	400	

Embedment Material	$E \times 10^{6}$ psi	ν
Plastic Clay	0.003	
Soil	0.001 to 0.02 [Ref 2]	0.25 to 0.45
Sand	0.02 to 0.06 [Ref 3]	0.28 to 0.35
Compacted Ottawa Sand	0.2	
Weathered Rock	0.04 to 0.11 [Ref 4]	
Concrete	5.0	0.25

Examples.

For an oil-filled cell, 9 inches diameter and D = 0.060 inches, totally embedded in:

1. Plastic Clay, E = 3000 psi, ν = 0.3,.....P = 0.042 psi / °C
2. Soil, medium stiffness, E = 10000 psi, ν = 0.3 ..... P = 0.138 psi / °C
3. Coarse Sand, E = 50000 psi, ν = 0.3.....P = 0.69 psi / °C

(For contact pressure cells, multiply the above values for P by 2.)

For a concrete stress cell, 9 inch diameter and D = 0.020 inches:

4. Concrete, E = 5×10^{6} psi, ν = 0.25 .....P = 22.7 psi / °C

Same cell, embedded in concrete, filled with mercury instead of oil, ... P = 5.8 psi / °C
For an oil-filled cell embedded in a completely rigid medium ..... P = 210 psi / °C
For a mercury-filled cell embedded in a completely rigid medium ..... P = 650 psi / °C

References:

[1] Roark, R.J. and Young, W.C. " Formulas for Stress and Strain," McGraw Hill, fifth edition, 1982, p 519.

[2] Weiler, W.A. and Kulhawy, F.H. " Factors Affecting Stress Cell Measurement in Soil" J. Geotech. Eng. Div. ASCE . Vol. 108, No. GT12, Dec., pp1529-1548.

[3] Lazebnik, G.E., "Monitoring of Soil-Structure Interaction." Chapman & Hall. pp 224

[4] Fujiyasu, Y. and Orihara, K. "Elastic Modulus of Weathered Rock." Proc. of the 5th Intl. Symp. on Field Measurements in Geomechanics - Singapore 1999. p 183

APPENDIX D - NON LINEARITY AND THE USE OF A SECOND ORDER POLYNOMIAL TO IMPROVE THE ACCURACY OF THE CALCULATED PRESSURE

Most vibrating wire pressure transducers are sufficiently linear (± 0.2 % FS) that use of the linear calibration factor satisfies normal requirements. However, it should be noted that the accuracy of the calibration data, which is dictated by the accuracy of the calibration apparatus, is always ± 0.1 % FS.

This level of accuracy can be recaptured, even where the transducer is non-linear, by the use of a second order polynomial expression which gives a better fit to the data then does a straight line. The polynomial expression has the form:

$$\text{pressure} = AR^2 + BR + C$$

where R is the reading (digits channel B) and A,B,C, are coefficients. Figure 15 on page 21 shows a typical calibration sheet of a transducer which has a very little non-linearity. The figure under the "Linearity (%FS)" column is

$$\frac{\text{Calculated pressure- True pressure}}{\text{Full-scale Pressure}} \times 100\% = \frac{G(R_1 - R_0) - P}{F.S} \times 100\%$$

Note The linearity is calculated using the regression zero for R_0 shown on the sheet.

For example, from the typical sheet shown in Figure 15, Page 21 when P= 210 kPa, G $(R_1 - R_0)$ = - 0.1192(7223-8983), gives a calculated pressure of 209.8 kPa. The error is 0.2 kPa. Whereas the polynomial expression gives a calculated pressure of A $(7223)^2$ + B (7223) + 1053 = 209.9 kPa and the actual error is only 0.01 kPa. This is an insignificant improvement but where the non-linearity is higher, say +/- 0,25%FS the improvement could be significant.

Note. If the polynomial equation is used it is important that the value of C, in the polynomial equation, be taken in the field, following the procedures described in section 2.1.1. The field value of C is calculated by inserting the initial field zero reading into the polynomial equation with the pressure, P, set to zero.

If the field zero reading is not available calculate C using the zero pressure reading on the calibration sheet. In the above example the value of C would be derived from the equation 0 = $A(8981)^2 + B(8981)$ from which C = +1053.

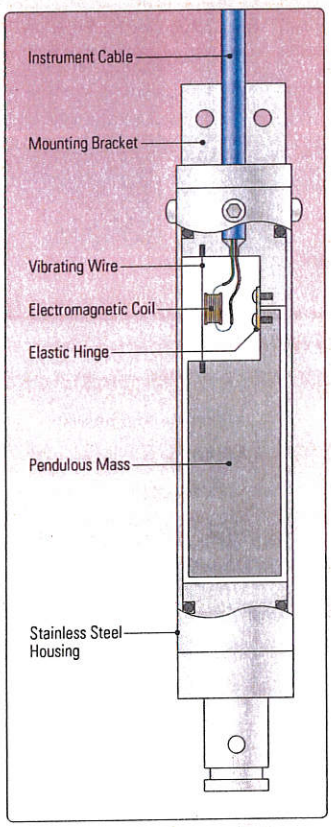
It should be noted that where changes of earh pressures are being monitored it makes little difference whether the linear coefficient or the polynomial expression is used.

Vibrating Wire Tiltmeter

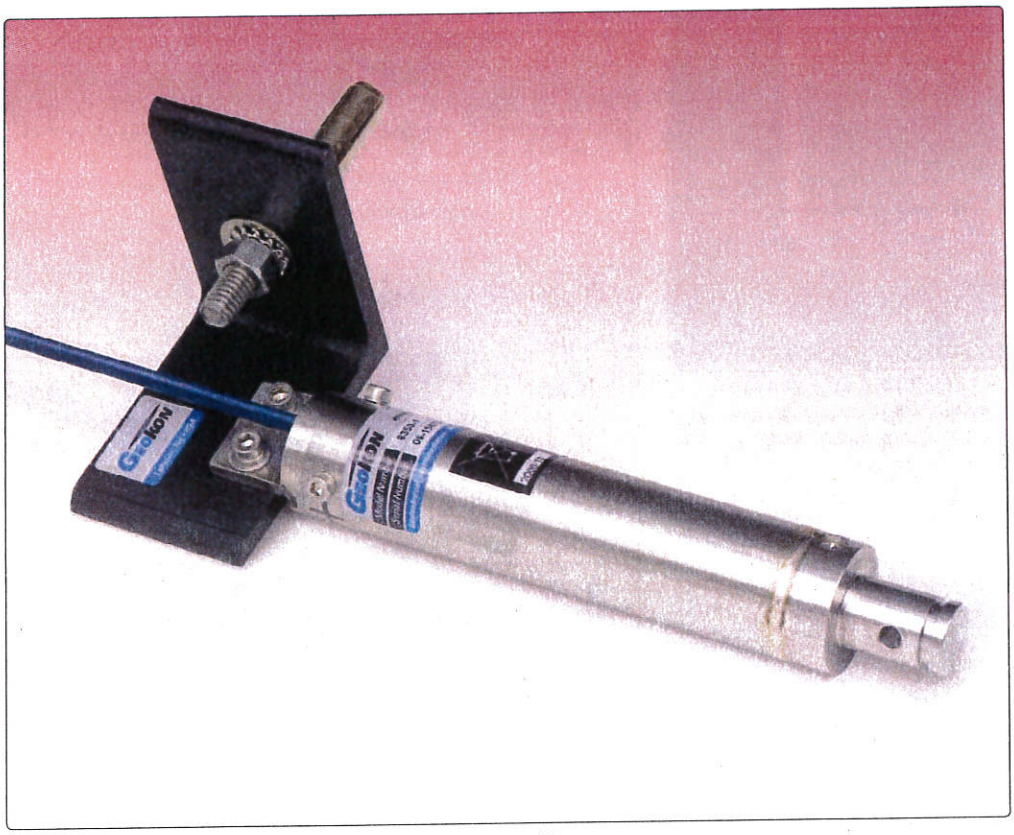
Applications

The Model 6350 Vibrating Wire Tiltmeter is designed to measure tilt in structures including...

- **Buildings**
- **Dams**
- **Embankments**
- **Slopes**
- **Excavation walls**
- **Open pits**



Vibrating wire tilt sensor construction.



Model 6350 Vibrating Wire Tiltmeter shown with mounting bracket assembly.

Operating Principle

The Model 6350 Tiltmeter is designed for attachment to structures, on either a vertical or horizontal surface by means of an adjustable bracket, and for the subsequent measurement of any tilting that may occur.

When at rest, in a vertical configuration, a pendulous mass inside the sensor, under the force of gravity, attempts to swing beneath the elastic hinge on which it is supported but is restrained by the vibrating wire. As the tilt increases or decreases the mass attempts to rotate beneath the hinge point and the tension in the vibrating wire changes, altering its vibrational frequency. This frequency is measured using the Geokon Model GK-401, GK-403 or GK-404 Readout Box, or the Micro-1000 Datalogger, and is then converted into an angular displacement by means of calibration constants supplied with the sensor.

Advantages and Limitations

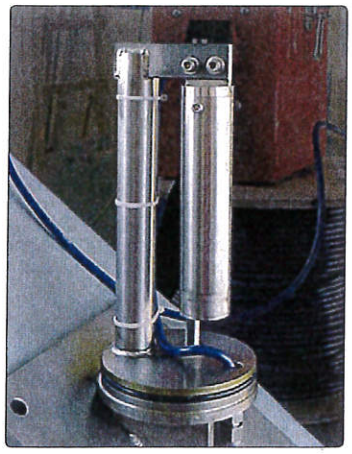
Vibrating wire tiltmeters combine a high range with high sensitivity, and very high calibration accuracy. They have excellent long-term stability and their temperature dependence is close to zero.

The sensor output is a frequency, which can be transmitted over long cables, and renders the sensors less susceptible to the effects of moisture intrusion.

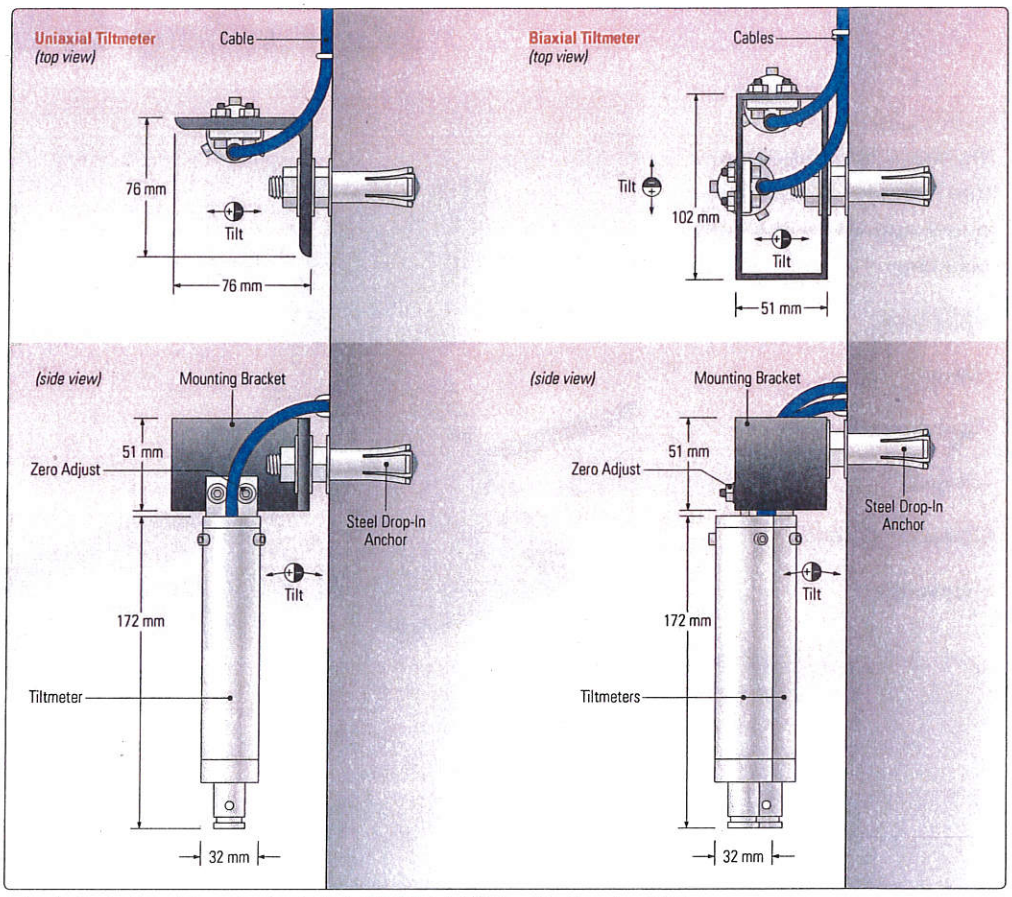
Biaxial measurements can be achieved by mounting the sensors in pairs, each member oriented at 90 degrees to the other.

Damping fluid may be added to the sensor to counteract the effect of any vibrations of the structure.

In-built shock absorbers protect the sensor from shock loading.



Model 6350 installation using a custom mounting bracket designed for concrete face rock fill dam applications (shown with protective cover removed).



Installation details and dimensions for the Model 6350 Uniaxial (left) and Biaxial versions (right).

System Components

The basic transducer is mounted inside a stainless steel housing equipped with a lug for mounting the sensor to an adjustable bracket. The bracket is bolted to the structure using hardware supplied with the sensor, which includes a 3/8-inch drop-in anchor. Special biaxial mounting brackets and protective enclosures are also available.

A thermistor mounted inside the sensor housing permits the measurement of temperatures.

Readout is accomplished using a Geokon Model GK-401, GK-403 or GK-404 Readout Box.

Technical Specifications

Standard Range[1]	±10°
Resolution	±0.05 mm/m (8 arc seconds)
Accuracy[2]	±0.1% F.S.
Temperature Range	–20°C to +80°C
Shock Survival	50 g
Length × Diameter[3]	172 × 32 mm

[1]*Other ranges available on request.*
[2]*Established under laboratory conditions.*
[3]*Transducer only.*

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The World Leader in Vibrating Wire Technology™

Geokon maintains an ongoing policy of design review and reserves the right to amend products and specifications without notice.

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Installation Manual

Model 6350

Vibrating Wire Tiltmeter

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1. INTRODUCTION

1.1. Theory of Operation

The Geokon Model 6350 Vibrating Wire Tiltmeter is designed for permanent long-term monitoring of changes in tilt of structures such as dams, embankments, foundation walls and the like. The basic principle is the utilization of tilt sensors attached to the structure being studied to make accurate measurement of inclination. See Figure 1.

Two brackets are available, one to measure tilt uniaxially the other biaxially.

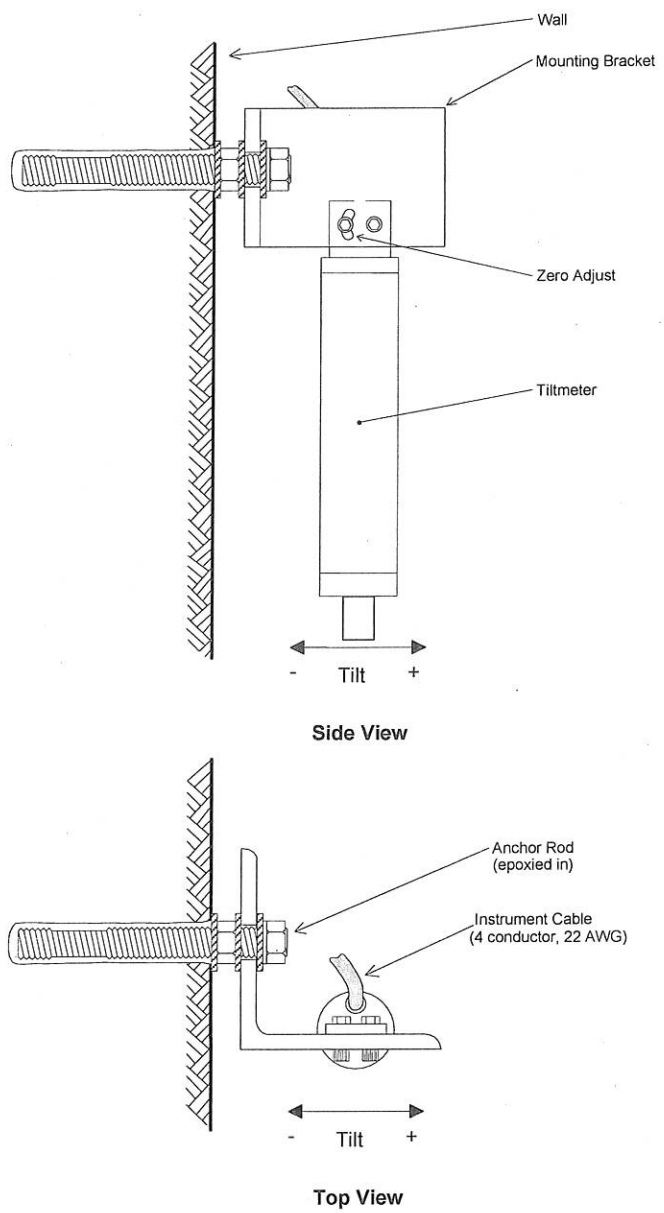

Figure 1 - Model 6350 Uniaxial Tiltmeter Installation

1.2. Tilt Sensor Construction

The sensor comprises a pendulous mass which is supported by a vibrating wire strain gage and an elastic hinge. See Figure 2. The strain gage senses the changes in force caused by rotation of the center of gravity of the mass. The mass and sensor are enclosed in a waterproof housing which includes components for connecting the sensor to the mounting bracket. The housing is constructed using stainless steel tubing to minimize the effects of corrosion. Biaxial systems use a mounting bracket to mount two transducers at 90° to each other. In environments subject to vibrations a damping fluid can be used, as shown in the figure below.

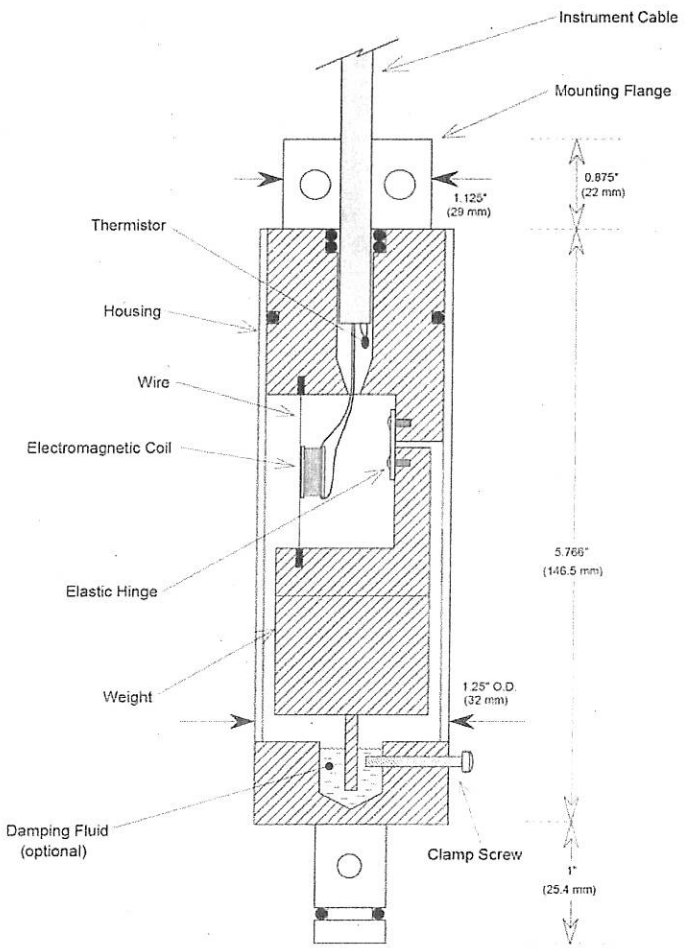

Figure 2 - Model 6350 Tilt Sensor

To prevent damage during shipment the tilt sensors are locked in place by means of a slotted-head locking clamp screw. This slotted-head locking clamp screw must be removed and replaced by a Phillips–head seal screw, (provided in a zip-lock bag)), to render the tiltmeter operative.

2. INSTALLATION

2.1. Preliminary Tests

Prior to installation, the sensors need to be checked for proper operation. Each tilt sensor is supplied with a calibration sheet which shows the relationship between readout digits and inclination. The tilt sensor electrical leads (usually the red and black leads) are connected to a readout box (see section 3) and the current reading compared to the calibration readings. After backing-off the clamp screw 3 full turns, carefully hold the sensor in a vertical position and observe the reading. It will take a few seconds to come to equilibrium and the sensor must be held in a steady position. The readings should be in the range of the factory reading, but will vary according to inclination. The indicated temperature should be close to ambient.

Note: Vibrating wire tilt sensors are shock sensitive and severe shocks can cause a permanent offset or even break the suspension.
(The unit will not survive a 2 ft. (.5 m) drop onto a hard surface.) When transporting the tiltmeter tighten the locking clamp screw.

Checks of electrical continuity can also be made using an ohmmeter. Resistance between the gage leads should be approximately 180 Ω, ±10 ohms. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately 14.7Ω/1000' or 48.5Ω/km, multiply by 2 for both directions). Between the green and white should be approximately 3000 ohms at 25° (see Table B-1), and between any conductor and the shield should exceed 2 megohm.

2.2. Installation Instructions

Two mounting brackets are available for the Model 6350. One is designed for uniaxial tilt measurements the other for biaxial. See Figure 3. Also, two types of bracket mounting hardware are available. The uniaxial tiltmeter installation instructions describe the use of the epoxied or grouted anchor rod while the biaxial instructions describe the drop-in anchor.

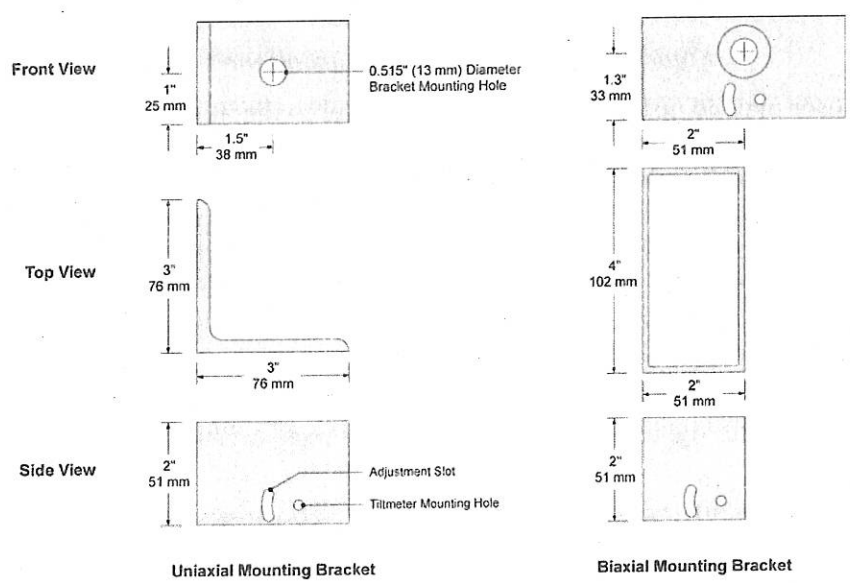

Figure 3 - Tiltmeter Mounting Brackets

Uniaxial Installation Instructions

1. The first step is to install the uniaxial mounting bracket (see Figure 3) which is designed for mounting on vertical walls.

   Mark the location and drill using a hammer drill a ½" (12 mm) hole approximately 4" (100 mm) deep. Clean the hole thoroughly, blowing out with compressed air if possible. Mix the grout or epoxy and fill the hole. Push the ½-13 threaded anchor rod into the hole, use a hammer if necessary to reach the bottom. Let the anchor rod set before continuing the installation. After setting, attach the mounting bracket to the bolt using the supplied hardware as illustrated in Figure 4. Use a bubble level or other leveling device to align the bracket vertically to the wall.

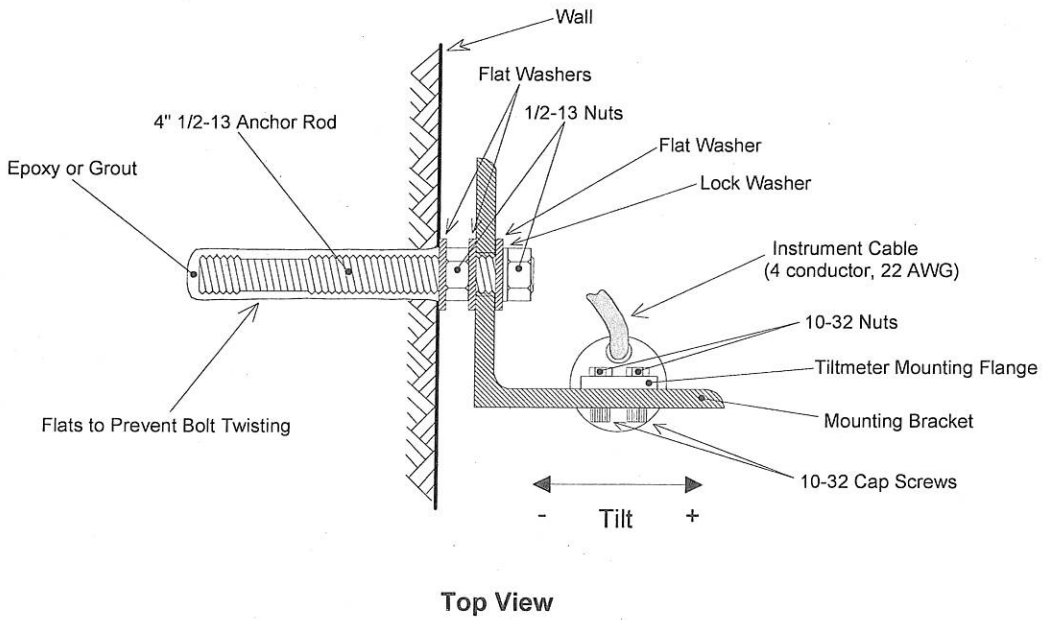

Figure 4 - Uniaxial Tiltmeter Installation Details

2. Now, the sensor may be installed. Attach the tiltmeter to the mounting bracket using the supplied 10-32 cap screws, washers and nuts. **Remove the slotted-head locking clamp screw completely and replace with the Phillips-head seal screw (provided in a zip-lock bag). This is very important if the sensor is to remain waterproof.** Do not tighten the cap screws yet. Attach a portable readout such as the GK-401 or GK-403 (see Section 3 for readout instructions) and observe the reading. Adjust the sensor in the slot of the mounting bracket while observing the readout until the tiltmeter reads within ±50 digits of the zero reading as shown on the calibration sheet (sample, Figure 5) supplied with the sensor. When the desired reading is reached, tighten the cap screws to secure the tiltmeter in place. Check the reading again after tightening to make sure it still reads within ±50 digits of the zero reading.

   If the tiltmeter is installed in an exposed location in a construction area and/or if the installation is in direct sunlight it should be covered with a protective enclosure and/or insulation.

Biaxial Installation Instructions

1. The first step is to install the biaxial mounting bracket (see Figure 3) which is designed for mounting on vertical walls.

   Mark the location and drill using a hammer drill a ½" (12 mm) hole approximately 1½" (37 mm) deep. Clean the hole thoroughly, blowing out with compressed air if possible. Insert the 3/8" drop-in anchor with setting pin into the hole. The threaded end should be closest to the opening. Using the supplied setting pin tool and a hammer, set the anchor with 2 or 3 sharp blows on the setting pin. Thread the supplied 3/8-16 anchor rod into the anchor. Attach the mounting bracket to the bolt using the supplied hardware as illustrated in Figure 5. Use a bubble level or other leveling device to align the bracket vertically to the wall.

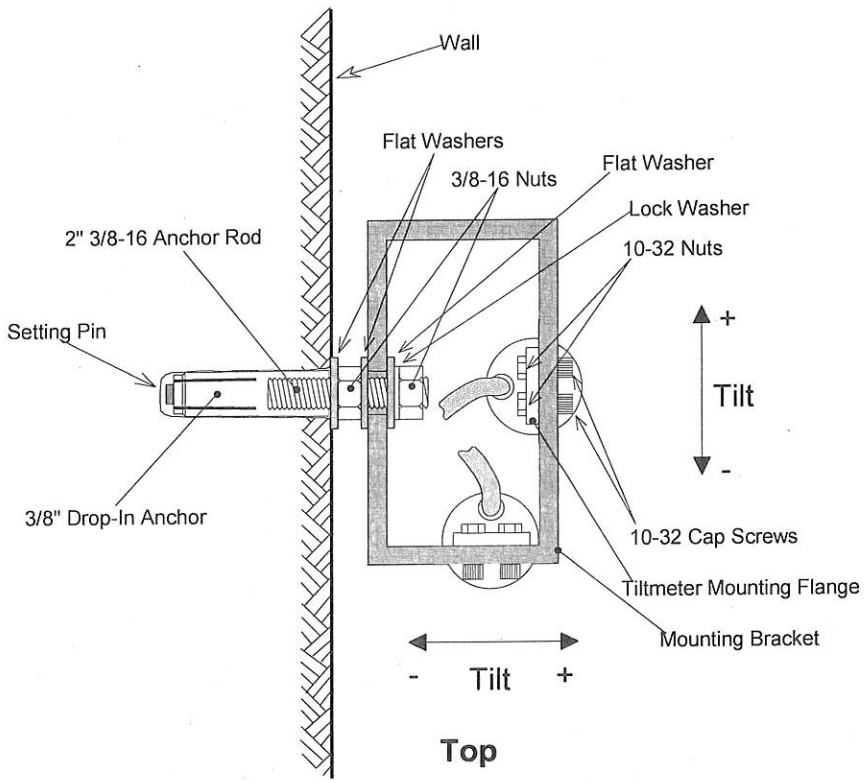

Figure 5 - Biaxial Tiltmeter Installation Details

2. Now, the sensors may be installed. Attach the tiltmeters to the mounting bracket using the supplied 10-32 cap screws, washers and nuts. **Remove the slotted-head locking clamp screw completely and replace with the Phillips-head seal screw provided. This is very important if the sensor is to remain waterproof.** Do not tighten the cap screws yet. Attach a portable readout such as the GK-401 or GK-403 (see Section 3 for readout instructions) and observe the reading. Adjust each sensor in their slots of the mounting bracket while observing the readout until the tiltmeter reads within ±50 digits of the zero reading as shown on the calibration sheet (sample, Figure 5) supplied with each sensor. When the desired reading is reached, tighten the cap screws to secure the tiltmeter in place. Check the reading again after tightening to make sure it still reads within ±50 digits of the zero reading.

   If the tiltmeters are installed in an exposed location in a construction area and/or if the installation is in direct sunlight it should be covered with a protective enclosure and/or insulation.

2.3. Fluid Damping

The vibrating wire tilt sensor acts as a self-damping system when used in vibration free environments. When external ground or structural vibrations exceed a certain threshold, the pendulous mass will continue to "swing" and stable readings may not be possible. In such cases, additional damping can be achieved by adding a viscous damping fluid to a small reservoir contained in the sensor. A thin, wide "paddle" is connected to the mass and when the fluid is added the pendulum is damped by the action of the paddle in the damping fluid (see Figure 2).

Most in-place tiltmeter installations will not require this fluid. However, if the instrument gives unstable outputs, or it is known that the structure is constantly vibrating, the fluid can be added. The fluid is a very high viscosity silicone oil which must be injected into the sensor with a syringe.

The sensor must be held upright during the injection of the fluid and at all times following the injection. This makes it necessary to perform this operation in the field. The following applies for a typical in-place installation.

1. Remove the seal screw on the bottom side of the sensor. See Figure 2.(clamp screw)
2. Using the syringe applied, first pull the piston from the syringe and squeeze the silicone from the tube into the syringe. Replace the piston and start the fluid out of the "needle" end.
3. Now, inject 2.00cc into the hole in the sensor. Immediately following this operation, the seal screw should be replaced in the sensor.
4. The sensor may now be attached to the mounting bracket.

2.4. Splicing and Junction Boxes

Because the vibrating wire output signal is a frequency rather than current or voltage, variations in cable resistance have little effect on gage readings and, therefore, splicing of cables has little effect and, in some case, may be beneficial. For example, if a number of tiltmeters are installed in a cluster, and the distance from the cluster to the terminal box or datalogger is great, a splice could be made to connect the individual cables to a single multi-conductor cable. This multiconductor cable would then be run to the readout station.

The cable used for making splices should be a high quality twisted pair type with 100% shielding (with integral shield drain wire). When splicing, it is very important that the shield drain wires be spliced together! Splice kits recommended by Geokon (i.e. 3M Scotchcast™, model 82-A1) incorporate casts placed around the splice then filled with epoxy to waterproof the connections. When properly made, this type of splice is equal or superior to the cable itself in strength and electrical properties. Contact Geokon for splicing materials and additional cable splicing instructions.

Junction boxes and terminal boxes are available from Geokon for all types of applications. In addition, portable readout equipment and datalogging hardware are available. Contact Geokon for specific application information.

2.5. Lightning Protection

The Model 6350 Tiltmeter, unlike numerous other types of instrumentation available from Geokon, does not have any integral lightning protection components, i.e. transzorbs or plasma surge arrestors. Usually this is not a problem. However, if the instrument cable is exposed, it may be advisable to install lightning protection components, as the transient could travel down the cable to the gage and possibly destroy it.

Note the following suggestions;

- If the tiltmeter is connected to a terminal box or multiplexer, components such as plasma surge arrestors (spark gaps) may be installed in the terminal box/multiplexer to provide a measure of transient protection. Terminal boxes and multiplexers available from Geokon provide locations for installation of these components.
- Lighting arrestor boards and enclosures are available from Geokon that install near the instrument. The enclosure has a removable top so, in the event the protection board (LAB-3) is damaged, the user may service the components (or replace the board). A connection is made between this enclosure and earth ground to facilitate the passing of transients away from the gage. See Figure 6. Consult the factory for additional information on these or alternate lightning protection schemes.
- Plasma surge arrestors can be epoxy potted into the gage cable close to the sensor. A ground strap would connect the surge arrestor to earth ground, either a grounding stake or other suitable earth ground.

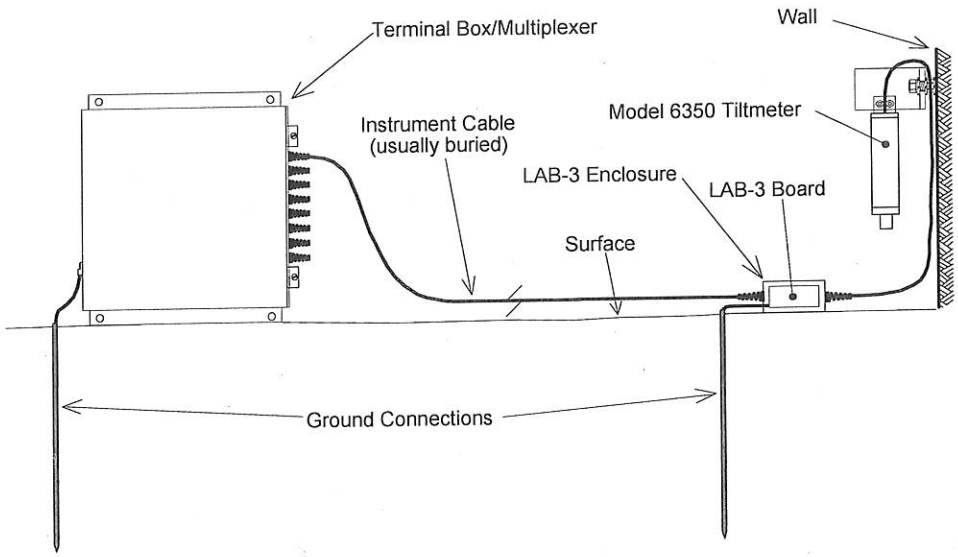

Figure 6 - Lightning Protection Scheme

3. TAKING READINGS

3.1. Operation of the GK-401 Readout Box

The GK-401 is a basic readout for all vibrating wire gages.

Connect the Readout using the flying leads or in the case of a terminal station, with a connector. The red and black clips are for the vibrating wire gage, the green or blue clip for the shield drain wire. The GK-401 cannot read the thermistor (see Section 3.4).

1. Turn the display selector to position "B". Readout is in digits (Equation 1).

2. Turn the unit on and a reading will appear in the front display window. The last digit may change one or two digits while reading. Record the value displayed. If zeros are displayed or the reading is unstable see section 5 for troubleshooting suggestions.

3. The unit will automatically turn itself off after approximately 4 minutes to conserve power.

3.2. Operation of the GK-403 Readout Box

The GK-403 can store gage readings and also apply calibration factors to convert readings to engineering units. Consult the GK-403 Instruction Manual for additional information on Mode "G" of the Readout. The following instructions will explain taking gage measurements using Mode "B".

Connect the Readout using the flying leads or in the case of a terminal station, with a connector. The red and black clips are for the vibrating wire gage, the white and green clips are for the thermistor and the blue for the shield drain wire.

1. Turn the display selector to position "B". Readout is in digits (Equation 1).

2. Turn the unit on and a reading will appear in the front display window. The last digit may change one or two digits while reading. Press the "Store" button to record the value displayed. If the no reading displays or the reading is unstable see section 5 for troubleshooting suggestions. The thermistor will be read and output directly in degrees centigrade.

3. The unit will automatically turn itself off after approximately 2 minutes to conserve power.

3.3 Operation of the GK404 Readout Box

The GK404 is a palm sized readout box which displays the Vibrating wire value and the temperature in degrees centigrade.
The GK-404 Vibrating Wire Readout arrives with a patch cord for connecting to the vibrating wire gages. One end will consist of a 5-pin plug for connecting to the respective socket on the bottom of the GK-404 enclosure. The other end will consist of 5 leads terminated with alligator clips. Note the colors of the alligator clips are red, black, green, white and blue. The colors represent the positive vibrating wire gage lead (red), negative vibrating wire gage lead (black), positive thermistor lead (green), negative thermistor lead (white) and transducer cable drain wire

(blue). The clips should be connected to their respectively colored leads from the vibrating wire gage cable.

Use the **POS** (Position) button to select position **B** and the MODE button to select **Dg** (digits). Other functions can be selected as described in the GK404 Manual.

The GK-404 will continue to take measurements and display the readings until the OFF button is pushed, or if enabled, when the automatic Power-Off timer shuts the GK-404 off.
The GK-404 continuously monitors the status of the (2) 1.5V AA cells, and when their combined voltage drops to 2V, the message **Batteries Low** is displayed on the screen. A fresh set of 1.5V AA batteries should be installed at this point

3.4. MICRO-10 Datalogger

The following parameters are recommended when using the Model 6350 with the MICRO-10 datalogger or any other CR10 based datalogger:

Excitation - The 2.5V excitation directly off the wiring panel is ideal for these sensors. The 5 volt supply from the AVW-1 and AVW-4 modules is also usable, but the 12V excitation should be avoided as it tends to overdrive the sensor. The default excitation voltage used in MICRO-10 systems is 5V.

Excitation Frequency - The starting and ending frequencies of the excitation sweep should be kept in a relatively narrow band for these sensors to maximize the stability and resolution of the output. The exact values can be calculated for a given sensor from the supplied calibration sheet. Ideally one could calculate settings by taking an initial reading and then setting the starting frequency to 200 Hz below and the ending frequency 200 Hz above. Alternately, the low end frequency sweep setting should be set to 14 (1400 Hz), the high end, 35 (3500 Hz).

3.5. Measuring Temperature

Each vibrating wire tiltmeter is equipped with a thermistor for reading temperature. The thermistor gives a varying resistance output as the temperature changes. Usually the white and green leads are connected to the internal thermistor.

1. Connect an ohmmeter to the two thermistor leads coming from the tilt sensor. (Since the resistance changes with temperature are so large, the effect of cable resistance is usually insignificant.)

2. Look up the temperature for the measured resistance in Table B-1. Alternately the temperature could be calculated using Equation B-1.

Note: The GK-403 readout box will read the thermistor and display temperature in °C automatically.

4. DATA REDUCTION

4.1. Tilt Calculation

Tilts are measured in digits on Position B of either the GK-401 or GK-403 Readout Box. The relationship between these digits and the change of the angle of inclination (tilt) is given by the equation:

$$\Delta\theta = (R_1 - R_0)\, G \qquad \text{degrees}$$

Where:

R_1 is the current reading in digits
R_o is the initial reading in digits
and G is the Calibration Factor in degrees/digit

The linear equation works very well for tilt angles of less than two degrees. More than this and the linearity errors increase. The error incurred by using the linear equation is shown on the calibration chart.

For better accuracy at larger inclinations use the polynomial equation:

$$\theta = R^2A + RB + C$$

Where A, B and C are the coefficients supplied on the calibration sheet. Calculate θ for $R = R_1$ and $R = R_0$ then subtract to find the difference $\Delta\theta$ for $(R_1 - R_0)$.

4.2. Temperature Correction

The Model 6350 Tiltmeter has a very slight temperature sensitivity on the order of – 0.5 digit per °C rise, i.e. the reading falls by 0.5 digits for every 1°C rise of temperature. The temperature correction is:

$$+K\,(T_1 - T_0) \qquad \text{degrees}$$

Where K = 0.5G

Normally, corrections are not applied for this small effect because the structure being monitored usually is affected to a much greater degree. An important point to note, also, is that sudden changes in temperature will cause both the structure and the Tiltmeter to undergo transitory physical changes, which will show up in the readings. The gage temperature should always be recorded for comparison, and efforts should be made to obtain readings when the instrument and structure are at thermal equilibrium. The best time for this tends to be in the late evening or early morning hours.

GEOKON 48 Spencer St. Lebanon, N.H. 03766 USA

Vibrating Wire Tilt Sensor Calibration

Model Number: 6350

Calibration Date: April 26, 2004

Serial Number: 04-4472

Temperature: 22.9 °C

Cal. Std. Control #(s): 406, 213, 260, 189, 524, 529, 333

Technician:

Inclination (sin)	Inclination (degrees)	* Reading 1st Cycle (digits)	* Reading 2nd Cycle (digits)	* Average Reading (digits)	Error (%FS) Linear	Error (%FS) Polynomial
0.0867	4.972	10469	10470	10470	-0.31	0.01
0.0667	3.823	9910	9912	9911	-0.20	0.01
0.0533	3.057	9540	9540	9540	-0.10	-0.02
0.0349	1.998	9023	9022	9023	-0.05	-0.01
0.0175	1.003	8535	8535	8535	-0.03	0.00
0.0087	0.497	8285	8287	8286	-0.04	0.02
0.0042	0.241	8161	8162	8162	-0.01	0.00
0.0000	0.000	8044	8044	8044	0.00	-0.01
-0.0042	-0.241	7926	7923	7925	-0.03	0.01
-0.0087	-0.497	7800	7800	7800	0.00	-0.01
-0.0175	-1.003	7551	7551	7551	-0.01	-0.01
-0.0349	-1.998	7059	7058	7059	-0.09	0.03
-0.0533	-3.057	6537	6536	6537	-0.14	0.00
-0.0667	-3.823	6159	6158	6159	-0.18	-0.02
-0.0867	-4.972	5587	5587	5587	-0.33	0.00

*Readings displayed in GK-401 Position B.

Linear Gage Factor (G): 0.002037 (degrees/ digit)

Polynomial Gage Factors: A: 5.084E-09 B: 1.955E-03 C: -16.053

Calculated Angle (degrees): Linear, $q = G(R_1 - R_0)+K(T_1-T_0)$

Polynomial, $q = AR^2 + BR + C$

Wiring Code: Red and Black: Gage White and Green: Thermistor Bare: Shield

The above instrument was found to be in tolerance in all operating ranges.

The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

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Figure 6 - Sample Model 6350 Calibration Sheet

5. TROUBLESHOOTING

Maintenance and troubleshooting of the vibrating wire tilt sensors used in the Model 6350 Tiltmeter are confined to periodic checks of cable connections. The sensors are sealed and there are no user-serviceable parts.

Consult the following list of problems and possible solutions should difficulties arise. Consult the factory for additional troubleshooting help.

Symptom: Tiltmeter Readings are Unstable

- ✓ Is the readout box position set correctly? If using a datalogger to record readings automatically are the swept frequency excitation settings correct? Channel A of the GK-401 and GK-403 can be used to read the tilt sensor. To convert the Channel A period display to digits use Equation 1.
- ✓ Is there a source of electrical noise nearby? Most probable sources of electrical noise are motors, generators and antennas. Make sure the shield drain wire is connected to ground whether using a portable readout or datalogger. If using the GK-401 Readout connect the clip with the green boot to the bare shield drain wire of the tilt sensor cable. If using the GK-403 connect the clip with the blue boot to the shield drain wire.
- ✓ Does the readout work with another tilt sensor? If not, the readout may have a low battery or be malfunctioning.

Symptom: Tiltmeter Fails to Read

- ✓ Is the cable cut or crushed? This can be checked with an ohmmeter. Nominal resistance between the two gage leads (usually red and black leads) is 180Ω, ±10Ω. Remember to add cable resistance when checking (22 AWG stranded copper leads are approximately 14.7Ω/1000' or 48.5Ω/km, multiply by 2 for both directions). If the resistance reads infinite, or very high (megohms), a cut wire must be suspected. If the resistance reads very low (<20Ω) a short in the cable is likely.
- ✓ Does the readout or datalogger work with another tilt sensor? If not, the readout or datalogger may be malfunctioning.

Symptom: Thermistor resistance is too high.

- ✓ Is there an open circuit? Check all connections, terminals and plugs. If a cut is located in the cable, splice according to instructions in Section 2.4.

Symptom: Thermistor resistance is too low.

- ✓ Is there a short? Check all connections, terminals and plugs. If a short is located in the cable, splice according to instructions in Section 2.4.
- ✓ Water may have penetrated the interior of the tilt sensor. There is no remedial action.

APPENDIX A - SPECIFICATIONS

A.1. Vibrating Wire Tilt Sensor

Model:	**6350**
Range:[1]	±10°
Resolution:[2]	8 arc seconds
Accuracy:[3]	+/- 8 arc seconds
Linearity:	+/- 0.3% FSR
Thermal Zero Shift:	+/- 4 arc seconds/°C
Operating Temperature	-40 to +80° C -40 to 175° F
Operating Frequency:	1400-3500 Hz
Coil Resistance:	180 Ω
Diameter:	1.250", 32 mm
Length:	7.375", 187 mm
Weight:	1.5 lbs., 0.7 kg.
Materials:	304 Stainless Steel
Electrical Cable:	2 twisted pair (4 conductor) 22 AWG Foil shield, PVC jacket, nominal OD=6.3 mm (0.250")

Table A-1 Model 6350 Tilt Sensor Specifications

Notes:
[1] Consult the factory for other ranges.
[2] Depends on readout equipment. With averaging techniques it is possible to achieve 1 arc second
[3] Derived using 2nd order polynomial.

A.2. Thermistor (see Appendix B also)

Range: -80 to +150° C
Accuracy: ±0.5° C

APPENDIX B - THERMISTOR TEMPERATURE DERIVATION

Thermistor Type: YSI 44005, Dale #1C3001-B3, Alpha #13A3001-B3

Resistance to Temperature Equation:

$$T = \frac{1}{A + B(LnR) + C(LnR)^3} - 273.2$$

Equation B-1 Convert Thermistor Resistance to Temperature

Where; T = Temperature in °C.
LnR = Natural Log of Thermistor Resistance
$A = 1.4051 \times 10^{-3}$ (coefficients calculated over the –50 to +150° C. span)
$B = 2.369 \times 10^{-4}$
$C = 1.019 \times 10^{-7}$

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
201.1K	-50	16.60K	-10	2417	+30	525.4	+70	153.2	+110
187.3K	-49	15.72K	-9	2317	31	507.8	71	149.0	111
174.5K	-48	14.90K	-8	2221	32	490.9	72	145.0	112
162.7K	-47	14.12K	-7	2130	33	474.7	73	141.1	113
151.7K	-46	13.39K	-6	2042	34	459.0	74	137.2	114
141.6K	-45	12.70K	-5	1959	35	444.0	75	133.6	115
132.2K	-44	12.05K	-4	1880	36	429.5	76	130.0	116
123.5K	-43	11.44K	-3	1805	37	415.6	77	126.5	117
115.4K	-42	10.86K	-2	1733	38	402.2	78	123.2	118
107.9K	-41	10.31K	-1	1664	39	389.3	79	119.9	119
101.0K	-40	9796	0	1598	40	376.9	80	116.8	120
94.48K	-39	9310	+1	1535	41	364.9	81	113.8	121
88.46K	-38	8851	2	1475	42	353.4	82	110.8	122
82.87K	-37	8417	3	1418	43	342.2	83	107.9	123
77.66K	-36	8006	4	1363	44	331.5	84	105.2	124
72.81K	-35	7618	5	1310	45	321.2	85	102.5	125
68.30K	-34	7252	6	1260	46	311.3	86	99.9	126
64.09K	-33	6905	7	1212	47	301.7	87	97.3	127
60.17K	-32	6576	8	1167	48	292.4	88	94.9	128
56.51K	-31	6265	9	1123	49	283.5	89	92.5	129
53.10K	-30	5971	10	1081	50	274.9	90	90.2	130
49.91K	-29	5692	11	1040	51	266.6	91	87.9	131
46.94K	-28	5427	12	1002	52	258.6	92	85.7	132
44.16K	-27	5177	13	965.0	53	250.9	93	83.6	133
41.56K	-26	4939	14	929.6	54	243.4	94	81.6	134
39.13K	-25	4714	15	895.8	55	236.2	95	79.6	135
36.86K	-24	4500	16	863.3	56	229.3	96	77.6	136
34.73K	-23	4297	17	832.2	57	222.6	97	75.8	137
32.74K	-22	4105	18	802.3	58	216.1	98	73.9	138
30.87K	-21	3922	19	773.7	59	209.8	99	72.2	139
29.13K	-20	3748	20	746.3	60	203.8	100	70.4	140
27.49K	-19	3583	21	719.9	61	197.9	101	68.8	141
25.95K	-18	3426	22	694.7	62	192.2	102	67.1	142
24.51K	-17	3277	23	670.4	63	186.8	103	65.5	143
23.16K	-16	3135	24	647.1	64	181.5	104	64.0	144
21.89K	-15	**3000**	**25**	624.7	65	176.4	105	62.5	145
20.70K	-14	2872	26	603.3	66	171.4	106	61.1	146
19.58K	-13	2750	27	582.6	67	166.7	107	59.6	147
18.52K	-12	2633	28	562.8	68	162.0	108	58.3	148
17.53K	-11	2523	29	543.7	69	157.6	109	56.8	149
								55.6	150

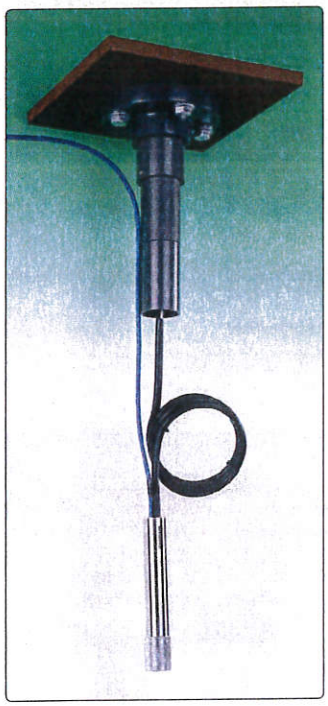
Table B-1 Thermistor Resistance versus Temperature

Vibrating Wire Settlement Systems

Applications

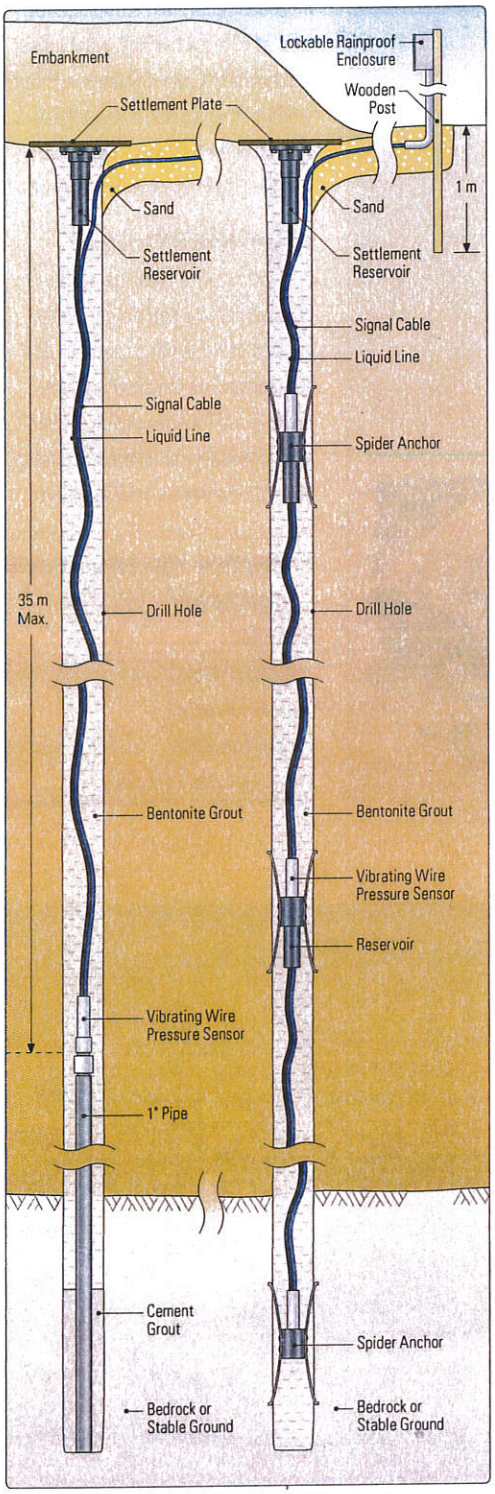
Settlement Systems are designed to measure the settlement of...

- **Dams**
- **Fills and embankments**
- **Foundations**
- **Roadways**
- **Storage tanks**
- **Surcharges**



Model 4600 Vibrating Wire Settlement System.

Model 4600 Settlement System



Typical Model 4600 (left) and 4600M (right) installations.

Operating Principle

The Model 4600 is designed for use where there is bedrock or stable ground, accessible by drilling a borehole, which can be used as a stable benchmark immediately beneath the point of settlement. A vibrating wire pressure sensor, anchored on a pipe grouted into solid ground or bedrock at the bottom of the borehole, is connected by a liquid-filled tube to a reservoir attached to a settlement plate located at the ground surface. As the fill is placed, the reservoir settles and the liquid pressure on the sensor diminishes. An electrical cable runs from the sensor to a remote readout location.

Where it is important to know in which subsurface zone settlement is occurring, a special version, the Model 4600M, can be used. It comprises of several 4600 systems, installed one above the other, in a single borehole. Intermediate combinations of reservoir and sensor are held in place in the borehole by leaf spring or hydraulic anchors.

Typical applications for the Model 4600 are: the measurement of sea-floor settlement beneath the construction of a sand-island, and the measurement of settlement beneath a surcharge in a swampy area.

Advantages and Limitations

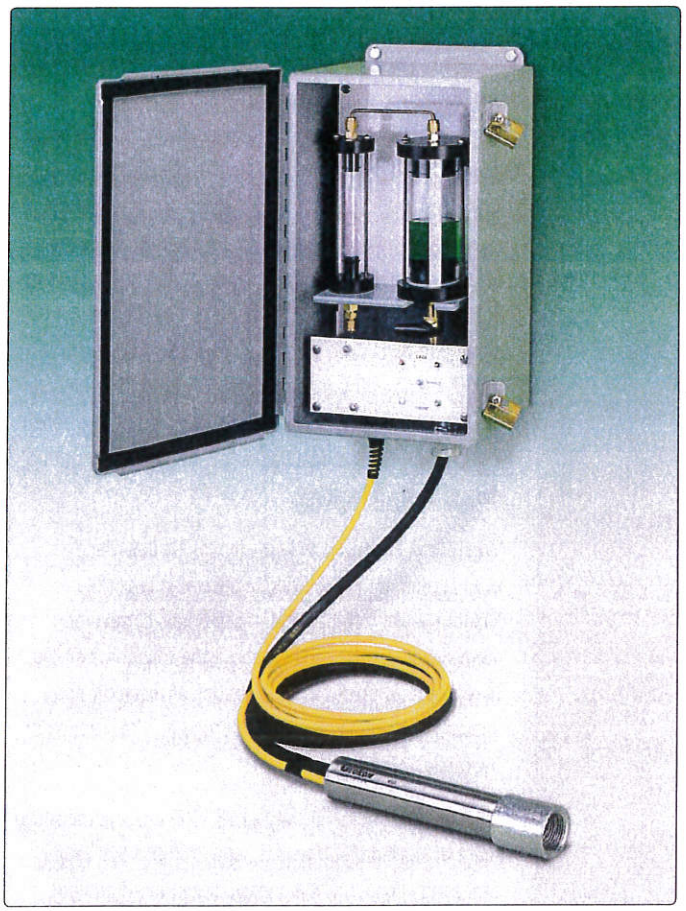
A closed loop vent line between transducer and reservoir prevents temperature and barometric pressure fluctuations from affecting the readings. The use of long horizontal liquid-filled tubes, which could be susceptible to air bubble formation, is not required. However, the proximity of stable ground beneath the settlement point and the drilling of a borehole are required. Systems are supplied fully sealed and assembled, ready for installation.

Technical Specifications

Standard Ranges[1]	7, 17, 35 m
Resolution	0.025% F.S.
Sensor Accuracy[2]	0.1% F.S.
Temperature Range	–20°C to +80°C
Length × Diameter	*(reservoir)* 305 × 60 mm *(sensor)* 191 × 35 mm

[1] *Other ranges available on request.*
[2] *Laboratory accuracy. Total system accuracy is subject to site-specific variables.*

Model 4650 Settlement System



• *Model 4650 Settlement System.*

Applications

The Model 4650 is designed for remote measurement of the settlement of a point in or below fills, surcharges, embankments, etc. Systems with tube lengths of up to 300 m have been used successfully to measure settlements in earth dam embankments.

Operating Principle

A vibrating wire pressure sensor is attached to a settlement plate located at the point of settlement. The sensor is connected via two liquid-filled tubes, extending laterally, to a reservoir located on stable ground. The sensor measures the hydraulic head of liquid between the sensor and reservoir locations.

Advantages and Limitations

A vented cable runs from the sensor to the remote readout location and connects to the reservoir so that barometric pressure fluctuations do not affect the readings.

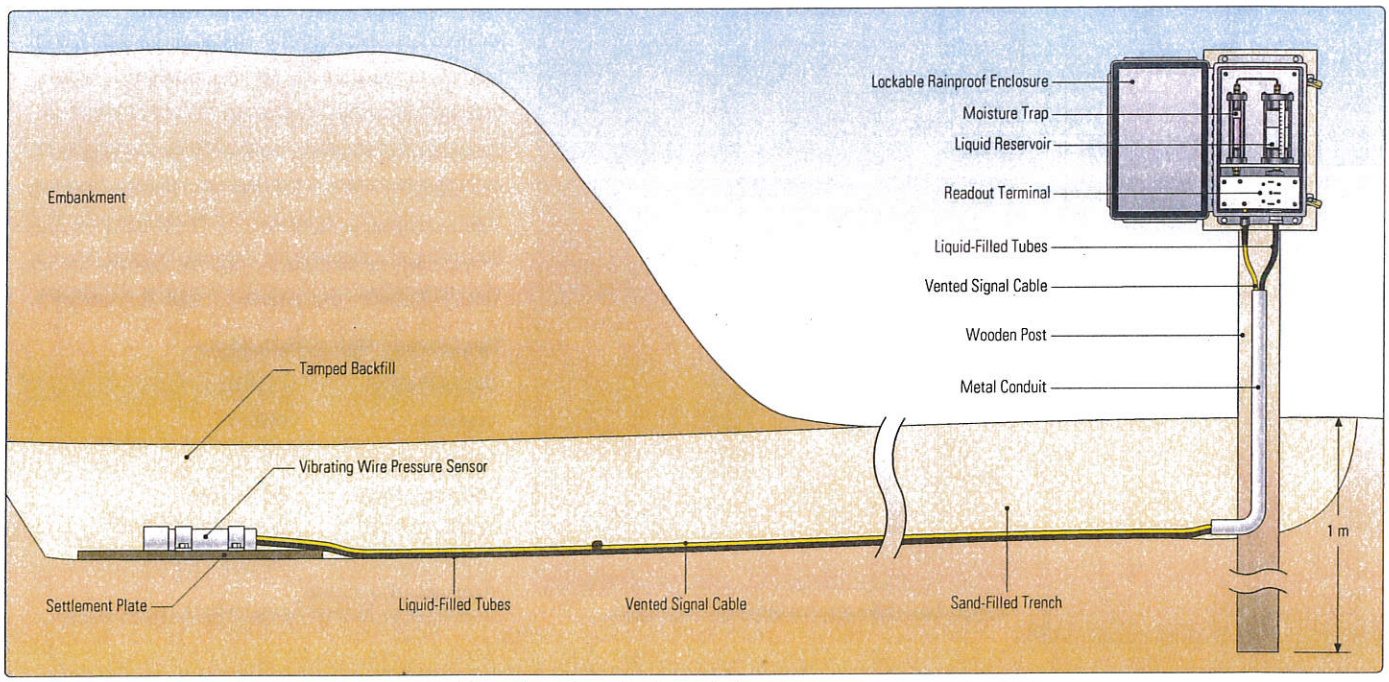
The liquid-filled tubes can be flushed to remove any air bubbles that might form.

It is possible to perform in-situ checks at any time on both the calibration and zero stability.

Technical Specifications

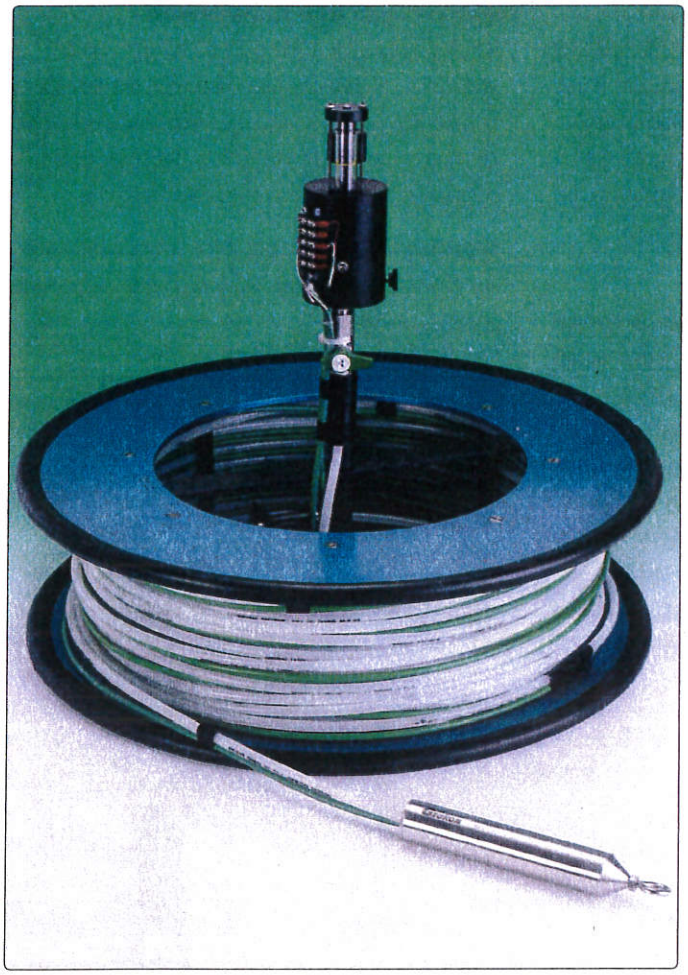
Standard Ranges[1]	7, 17 m
Resolution	0.025% F.S.
Sensor Accuracy[2]	0.1% F.S.
Temperature Range	–20°C to +80°C
Length × Diameter	*(reservoir)* 152 × 51 mm, *(sensor)* 191 × 35 mm

[1]*Other ranges available on request.*
[2]*Laboratory accuracy. Total system accuracy is subject to site-specific variables.*



• *Model 4650 installation for the remote measurement of subsurface settlement beneath a large embankment.*

Model 4651 Settlement Profiler



• *Model 4651 Settlement Profiler.*

Applications

The Model 4651 Settlement Profiler is a portable device designed to measure profiles of heave and settlement beneath fills, embankments, roadways, storage tanks, structures, etc. It can be used to measure differential settlements at discrete points on structures such as building columns, etc., and also to monitor surface settlement above tunneling activities.

Operating Principle

A sensitive Vibrating Wire Pressure Sensor is located inside a torpedo that can be pulled through a buried pipe, or carried from point to point. The Sensor is connected, via a liquid-filled tube, to a reservoir located on stable ground. The tubing is stored on a reel, which is mounted horizontally at the reservoir location, and is free to turn as the torpedo is pulled into the hole, or, is positioned at different locations. The sensor measures the hydraulic head between the reservoir and the sensor locations.

Advantages and Limitations

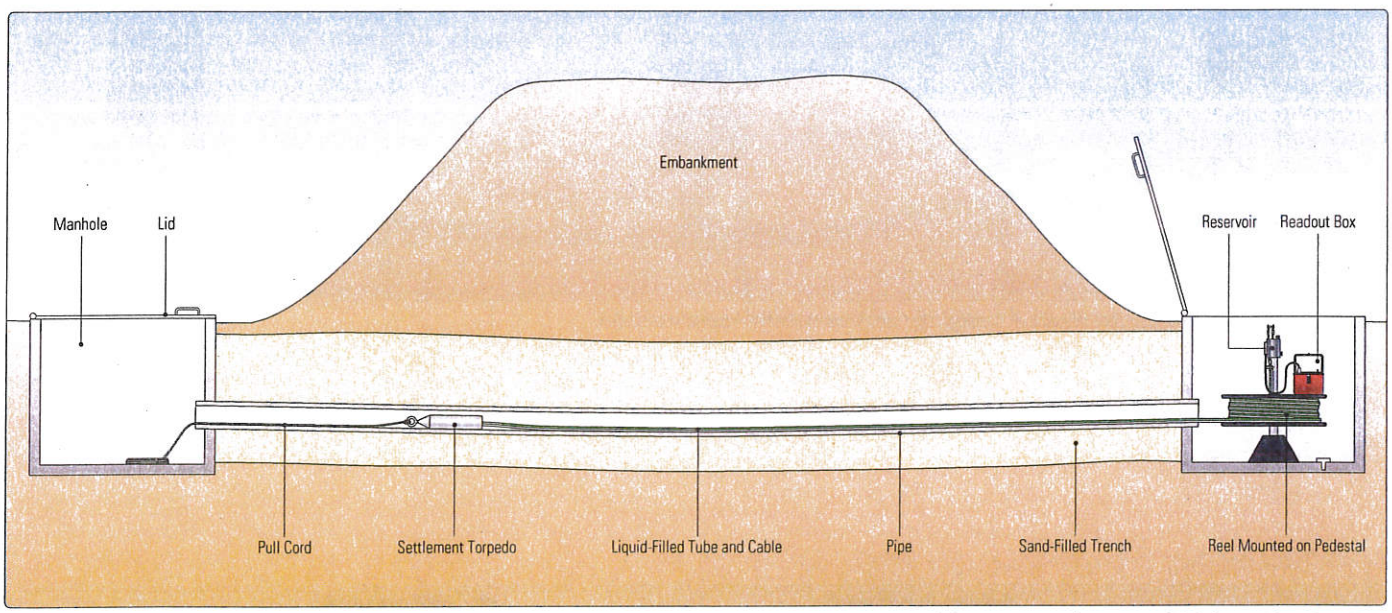
Independent measurements of settlement can be made at closely spaced intervals providing a detailed profile of differential settlements over a wide area.

The Sensor is vented so that barometric pressure fluctuations have no effect on the readings.

Technical Specifications

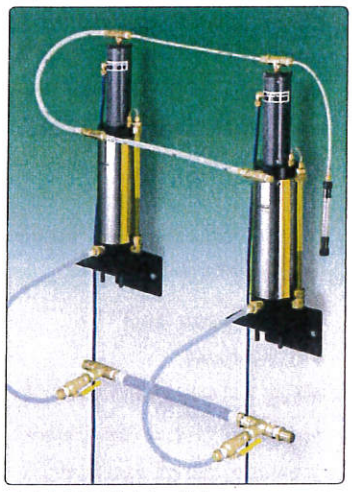
Standard Range[1]	7 m
Resolution	0.025% F.S.
Sensor Accuracy[2]	0.1% F.S.
Temperature Range	–20°C to +80°C
Length × Diameter	*(probe)* 203 × 35 mm, *(reel)* 178 × 610 mm

[1] *Other ranges available on request.*
[2] *Laboratory accuracy. Total system accuracy is subject to site-specific variables.*



• *Model 4651 installation used to measure and monitor embankment settlement. As an alternative installation, the empty manhole (shown above at left) and open-ended pipe may be replaced by a capped pipe with a pulley and return cable to pull and position the torpedo from the reel end of the pipe (shown above at right).*

Model 4675 High Sensitivity Settlement System



• *Model 4675 High Sensitivity Settlement System.*

Applications

The Model 4675 is designed to detect and measure very small changes of elevation at discrete locations. It has been used to measure differential settlements along tunnels, deflections of bridges and bridge piers, the settlement of building columns and floor slabs, etc. (i.e. situations in which high sensitivity is essential).

Operating Principle

A series of vessels are interconnected by a liquid-filled tube. One reference vessel is located on stable ground and the other vessels are located at the points of settlement. Each vessel contains a cylindrical weight suspended from a vibrating wire transducer. The common liquid level inside each vessel partially submerges the hanging weights; settlement of a vessel causes an apparent rise of the water level in that vessel leading to a greater buoyancy force on the weight and a reduction in the tension and frequency of the vibrating wire.

Advantages and Limitations

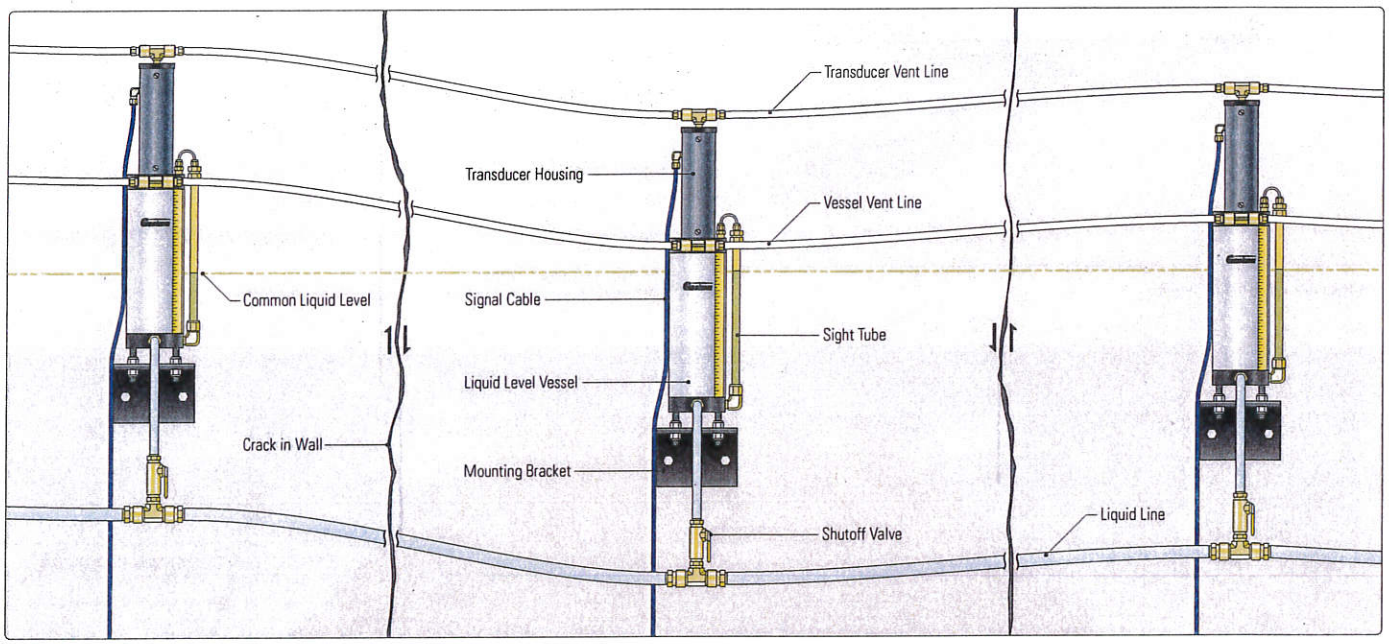
Very high resolution, of the order of 0.07 mm, can be attained. A vent line connected to each of the ves-sels prevents the readings from being affected by ambient air currents and barometric fluctuations. The readings are not significantly affected by temperature changes.

The vessels must be installed at the same elevation and the connecting liquid-filled tubing must remain below the vessels at all points.

Technical Specifications

Standard Ranges[1]	100, 150, 300, 600 mm
Resolution	0.025% F.S.
Sensor Accuracy[2]	0.1% F.S.
Temperature Range	–20°C to +80°C (using antifreeze solutions)
Dimensions	depends on range

[1]Other ranges available on request.
[2]Laboratory accuracy. Total system accuracy is subject to site-specific variables.



• *Installation of the Model 4675 on a concrete wall with exaggerated settlement to illustrate change in elevation.*

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The World Leader in Vibrating Wire Technology™

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Instruction Manual

Model 4600

VW Settlement Sensor

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(Doc Rev E, 4/09)

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Model 4600M Multilevel Settlement Monitoring System 9

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1. General Description

The 4600 Settlement System is designed to measure the settlement of a point relative to a point located immediately below it, in solid ground (bedrock). The usual method of installation is shown in Figure 1.

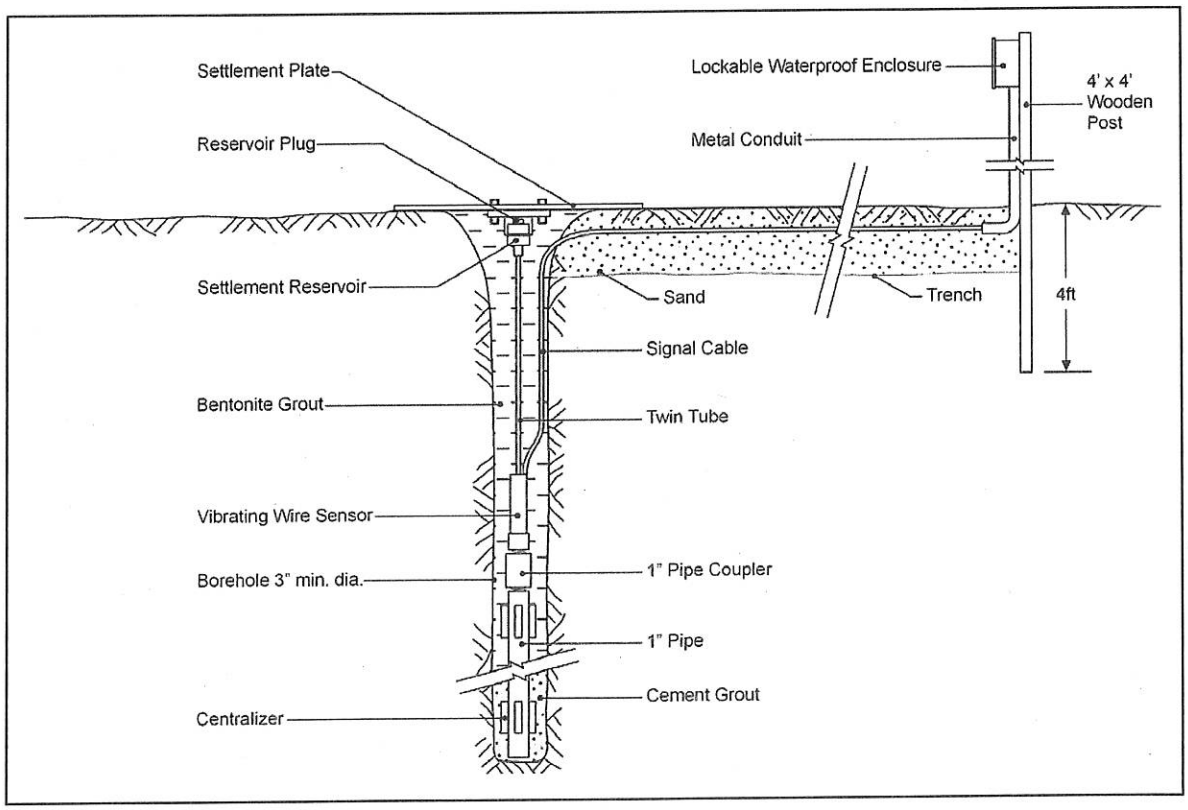


Figure 1. Model 4600 V.W. Settlement System.

The 4600 system has the disadvantage of requiring a borehole to reach solid ground but has the distinct advantage of avoiding the necessity for long horizontal runs of liquid-filled tubing to a remote readout location. The system is particularly suited to the measurement of settlements below sand islands constructed in marine environments.

A series of 4600 system, installed vertically above each other in a single borehole, can be used to monitor subsurface settlements at different elevations.

A pressure sensor is located in solid ground by attaching it to the upper end of a steel pipe, or rod, placed inside a borehole drilled to bedrock. The lower end of the pipe is grouted in place. A liquid-filled tube extends upwards from the sensor to the reservoir, which is attached to a settlement plate.

The settlement plate, usually located at the ground surface, (i.e. the elevation of the mouth of the borehole) settles with the ground, thus altering the height of the liquid column inside the liquid tube above the sensor. The sensor detects the change in liquid pressure and is read by means of an electrical cable running up the borehole and then horizontally to the readout location.

Standard systems are filled with either de-aired water or de-aired antifreeze solution, with chemicals added to prevent the growth of algae. The system is "closed" in that the inside of the sensor is connected, via a vent line,

to the space above the reservoir. A desiccant chamber prevents moisture from entering the vent line from the reservoir.

This arrangement ensures that the sensor readings are not influenced by temperature changes inside the reservoir, or by changes in barometric pressure. Details of the reservoir assembly are shown in Figure 2.

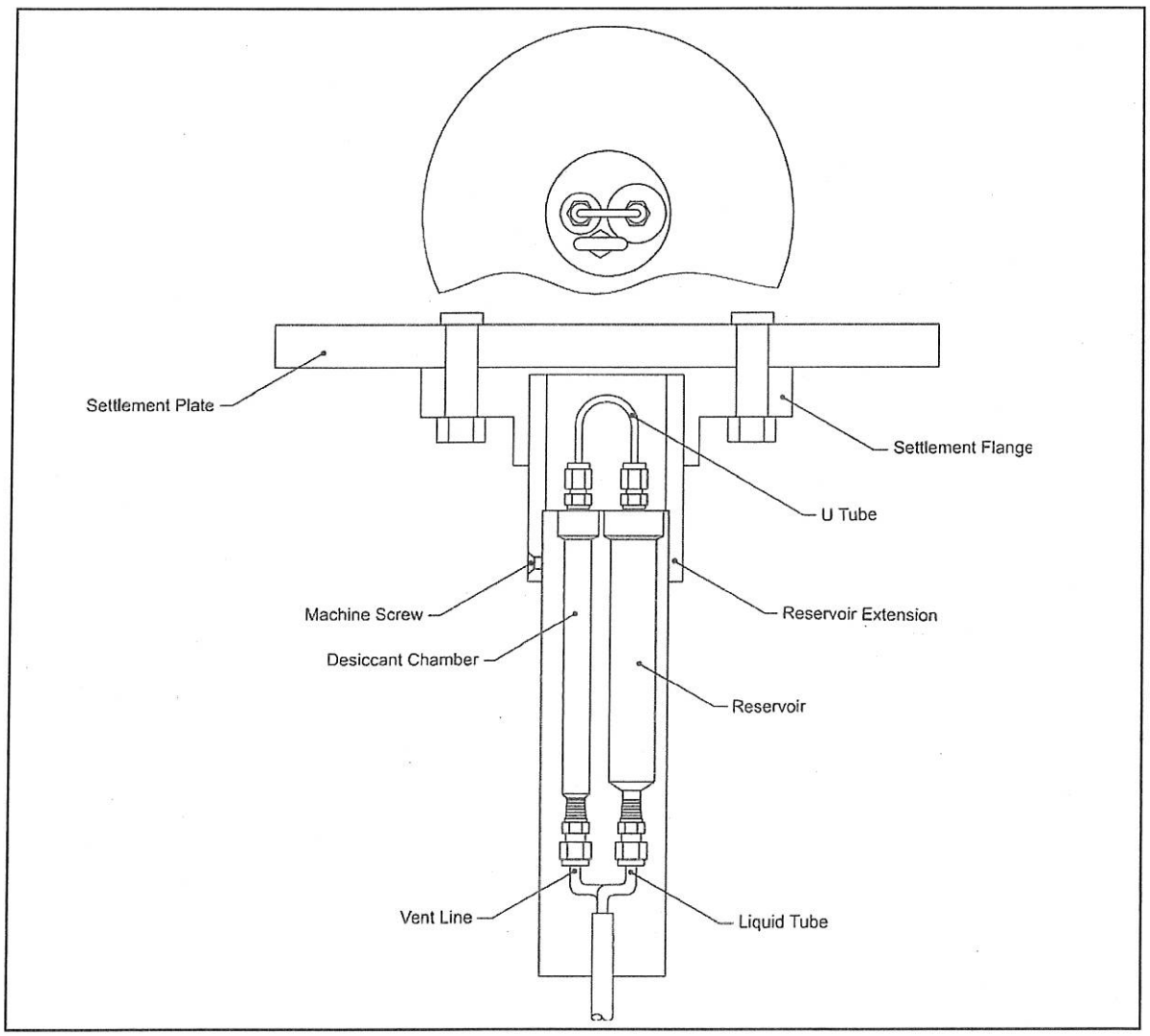


Figure 2. Model 4600 Settlement System – Reservoir Details

Readout is accomplished by GK-401 or GK-403 Readout Boxes or by the MICRO-10 Datalogger. The sensor contains a thermistor for the measurement of temperatures and also gas-discharge tubes for lighting protection.

2. Installation Procedures

2.1 Borehole Requirements

Installation generally requires a borehole to be drilled. The required borehole diameter is 75mm (3") or larger. Any casing, if used, should have an inner diameter greater than 70mm (2 ½"). The recommended distance between the sensor and the reservoir for the standard sensor range (7 meters) is 3 to 5 meters. The minimum spacing can be smaller so long as the spacing exceeds 3 times the anticipated maximum settlement. Thus if the anticipated maximum settlement is 0.5 meters, the sensor/reservoir spacing can be as close as 1.5 meters.

2.2

The Model 4600 Assembly is usually shipped with the liquid tube pre-filled with de-aired liquid. The liquid tube is of such a length to accommodate the spacing between sensor and reservoir specified at the time of ordering. Measure the depth of the borehole and prepare a length of pipe, (1" water-pipe is ideal), which will place the sensor at the desired elevation, (usually from 3 to 5 meters below the surface depending on the anticipated settlement, as previously discussed.)

2.3

Attach the sensor to the upper end of the pipe (the sensor normally has a matching thread built into it). Tie a long piece of rope to the upper end of the pipe and lightly tape a grout pipe to the lower end of the pipe. Lower the pipe into the borehole until it rests on the bottom.

2.4

Tremie full strength grout into the bottom 1.5 meters of the borehole. Pull the grout-pipe up 2 meters and tremie in a soft bentonite grout until the borehole is full.

2.5

If the hole is cased, the casing can now be removed. But first, tie the reservoir and signal cable to the rope and tie the rope to the top of the drill mast so that the casing can slide over and around the reservoir and signal cable as the casing is removed from the borehole.

2.6

4600 Settlement Systems are usually shipped with the reservoir completely filled with de-aired liquid so that there is no danger of air bubbles entering the liquid tube during shipment. To put the 4600 system into service it is necessary, now, to remove 10cc of liquid from the top of the reservoir and to connect the top of the reservoir to the desiccant chamber and vent line. Grip the Swagelock cap on top of the reservoir and pull the reservoir plug out of the top of the reservoir, (the larger of the two Delrin plugs). A syringe is provided for removal of the liquid and a short copper U-tube is supplied, with fittings, to be connected to the top of the reservoir after removal of the two Swagelock caps. Before replacing the reservoir plug and connecting the U-tube, add a few drops of light oil to the surface of the liquid to prevent evaporation.

2.7

Attach the settlement flange to the settlement plate using the bolts supplied.

2.8

While holding the reservoir in an upright position at all times, the settlement flange and plate can now be attached to the reservoir using the two machine screws provided or by using PVC cement obtained locally. (Federal Regulations prohibit the shipment of PVC cement). Apply PVC cement to the inside of the reservoir extension (see Figure 2) and to the outside of the top of the reservoir housing.

Be careful at all times not to allow the reservoir to tip over on its side which would allow liquid to enter the vent line.

2.9

Position the settlement flange at the top of the borehole and dig a trench leading from the borehole to the readout location into which the signal cable can be buried. Avoid sharp bends where the cable exits the borehole by excavating a broad sweep from the borehole to the trench (see Figure 1).

2.10

Bury the signal cable in the trench using sand or other fine grain materials around the cable to protect the cable from damage.

2.11

Terminate the signal cable inside a readout enclosure mounted on a post or pipe driven into the ground at the readout location.

3. Taking Readings

Take the initial reading, R_0, several times to ensure a good baseline reading. Read the temperature also. An insitu calibration check, of sorts, can be effected by raising the reservoir flange by a measured amount and observing the change in readout thus produced. Compare this calibration with the factory calibration. Alternatively, the initial gage reading, when converted to a height of liquid column, should correspond with the known difference in elevation between the reservoir and sensor.

Readings should be taken by a Model GK-401,GK-403 or GK-404 Readout Box set to display position B. Where a Micro 10 Datalogger is used the frequency limits should be set between 1400 to 3500 H_z.

The black and red conductors are connected to the vibrating wire sensor and the green and white conductors to the thermistor.

When taking initial readings conduct a level survey to determine the elevation, E_0, of the settlement flange.

3.1. Measuring Temperatures

Each vibrating wire settlement sensor is equipped with a thermistor for reading temperature. The thermistor gives a varying resistance output as the temperature changes. Usually the white and green leads are connected to the internal thermistor. The GK-401 Readout Box does not read temperatures – a digital ohmmeter is required.

1. Connect the ohmmeter to the two thermistor leads coming from the transducer. (Since the resistance changes with temperature are so large, the effect of cable resistance is usually insignificant.)

2. Look up the temperature for the measured resistance in Appendix A. Alternately the temperature could be calculated using the Equation in appendix A.

Note: The GK-403 and GK-404 readout boxes will read the thermistor and display temperature in °C automatically.

4. Data Reduction

4.1

The elevation, E, of the settlement flange at subsequent measurement times is given by the equation.

$$\mathbf{E = E_0 - (R_1 - R_0)\, G}$$

where $\mathbf{R_0}$ is the initial reading on channel B,

$\mathbf{R_1}$ is the subsequent reading on channel B,

and $\mathbf{G}$ is the calibration factor supplied with the sensor.

A typical calibration sheet, as supplied by the factory, is shown in Figure 3 (page 6).

$\mathbf{E_0}$ = 541.623 meters

$\mathbf{R_0}$ = 6030

$\mathbf{R_1}$ = 6800

$\mathbf{G}$ = 1.78 mm/digit

$\mathbf{E}$ = 541.623 – (6800 – 6030) 1.78 x 10^{-3}

$\mathbf{E}$ = 540.252 meters

Or, in other words, there has been a settlement of 1.371 meters.

4.2 Corrections for temperature

Usually, since the 4600 system is completely buried, temperature effects are negligible.

The temperature correction to the **elevation,** $\mathbf{E_T}$, is given by.

$$\mathbf{E_T = E_0 - (R_1 - R_0)\, G + (T_1 - T_0)\, K}$$

The amount of settlement, **S**, of the sensor is given by the equation

$$\mathbf{S = (R_1 - R_0)\, G}$$

And the temperature correction to the **settlement,** **S**, is given by:

$$\mathbf{S = (R_1 - R_0)\, G - (T_1 - T_0)\, K}$$

where T_0 is the initial temperature in °C,

T_1 is the subsequent temperature in °C,

and **K** is the temperature correction factor given on the calibration sheet.

5. Maintenance and Trouble Shooting

Since all the 4600 Settlement System components are buried there is no maintenance to observe and little can be done in the event the readings become suspect. Unstable readings, especially with data loggers, may be caused by electrical noise form nearby power lines or electrical equipment. Make sure that the ground conductor is connected to the ground on the datalogger, or to the blue clip on the GK401 or GK403 patchcord.

Resistance between the black and red conductors should be 180 ohms ± 10 ohms plus 5 ohms for every 100 meters of lead wire.

Resistance between the green and white wires depends on the temperature as shown by the Thermistor Chart in Appendix A (page 7).

GEOKON

Settlement System Calibration

Model Number: 4600-1-10

Serial Number: 40913

Transducer Number: 7-531

Customer I.D. #: SSW2-6

Customer:

Job Number: 10681

Date: 8/11/97

Transducer Size: 10 psi (vented)

Tested By:

Temperature: 23.4 °C

Tubing: 3/16 twin x 1090'

Cable: 2 pr. yellow x 1090'

Elevation	Reading GK 401 Pos. B	Difference
2'	9903.6	
3'	9751.4	152.2
4'	9597.7	153.7
5'	9443.7	154.0
6'	9289.1	154.6
7'	9135.6	153.5
8'	8983.3	152.3

153.38 Average Digits per 12 inches

12.78 Average Digits per Inch

0.07824 Inches per Digit

-0.11187 Thermal Factor (inches/°C.)

Wiring Code

Red and Black: Gage

White and Green: Thermistor

The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

Figure 3. Typical Calibration Sheet

Appendix A:

Thermistor Linearization using Steinhart and Hart Log Equation

Tech Memo 91-03 Doc Rev 6-94, Geokon, Inc.

Thermistor Type: YSI 44005, Dale #1C3001-B3, Alpha #13A3001-B3

Basic Equation:

$$T = \frac{1}{A + B(\mathrm{LnR}) + C(\mathrm{LnR})^3} - 273.2$$

where:

T = Temperature in °C.

LnR = Natural Log of Thermistor Resistance

A = 1.4051×10^{-3}

B = 2.369×10^{-4}

C = 1.019×10^{-7}

Note: Coefficients calculated over -50° to +150°C. span.

Resistance versus Temperature Table

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
201.1K	-50	16.60K	-10	2417	+30	525.4	+70	153.2	+110
187.3K	-49	15.72K	-9	2317	31	507.8	71	149.0	111
174.5K	-48	14.90K	-8	2221	32	490.9	72	145.0	112
162.7K	-47	14.12K	-7	2130	33	474.7	73	141.1	113
151.7K	-46	13.39K	-6	2042	34	459.0	74	137.2	114
141.6K	-45	12.70K	-5	1959	35	444.0	75	133.6	115
132.2K	-44	12.05K	-4	1880	36	429.5	76	130.0	116
123.5K	-43	11.44K	-3	1805	37	415.6	77	126.5	117
115.4K	-42	10.86K	-2	1733	38	402.2	78	123.2	118
107.9K	-41	10.31K	-1	1664	39	389.3	79	119.9	119
101.0K	-40	9796	0	1598	40	376.9	80	116.8	120
94.48K	-39	9310	+1	1535	41	364.9	81	113.8	121
88.46K	-38	8851	2	1475	42	353.4	82	110.8	122
82.87K	-37	8417	3	1418	43	342.2	83	107.9	123
77.66K	-36	8006	4	1363	44	331.5	84	105.2	124
72.81K	-35	7618	5	1310	45	321.2	85	102.5	125
68.30K	-34	7252	6	1260	46	311.3	86	99.9	126
64.09K	-33	6905	7	1212	47	301.7	87	97.3	127
60.17K	-32	6576	8	1167	48	292.4	88	94.9	128
56.51K	-31	6265	9	1123	49	283.5	89	92.5	129
53.10K	-30	5971	10	1081	50	274.9	90	90.2	130
49.91K	-29	5692	11	1040	51	266.6	91	87.9	131
46.94K	-28	5427	12	1002	52	258.6	92	85.7	132
44.16K	-27	5177	13	965.0	53	250.9	93	83.6	133
41.56K	-26	4939	14	929.6	54	243.4	94	81.6	134
39.13K	-25	4714	15	895.8	55	236.2	95	79.6	135
36.86K	-24	4500	16	863.3	56	229.3	96	77.6	136
34.73K	-23	4297	17	832.2	57	222.6	97	75.8	137
32.74K	-22	4105	18	802.3	58	216.1	98	73.9	138
30.87K	-21	3922	19	773.7	59	209.8	99	72.2	139
29.13K	-20	3748	20	746.3	60	203.8	100	70.4	140
27.49K	-19	3583	21	719.9	61	197.9	101	68.8	141
25.95K	-18	3426	22	694.7	62	192.2	102	67.1	142
24.51K	-17	3277	23	670.4	63	186.8	103	65.5	143
23.16K	-16	3135	24	647.1	64	181.5	104	64.0	144
21.89K	-15	**3000**	**25**	624.7	65	176.4	105	62.5	145
20.70K	-14	2872	26	603.3	66	171.4	106	61.1	146
19.58K	-13	2750	27	582.6	67	166.7	107	59.6	147
18.52K	-12	2633	28	562.8	68	162.0	108	58.3	148
17.53K	-11	2523	29	543.7	69	157.6	109	56.8	149
								55.6	150

Appendix B:

Model 4600M Multilevel Settlement Monitoring System

General Description.

The Model 4600M multilevel is designed for installation in boreholes: it is not recommended for installation in fills while the fill is being placed. A drawing of the assembly is shown on page 10. A more detailed drawing of the Reservoir is shown below in Figure 4.

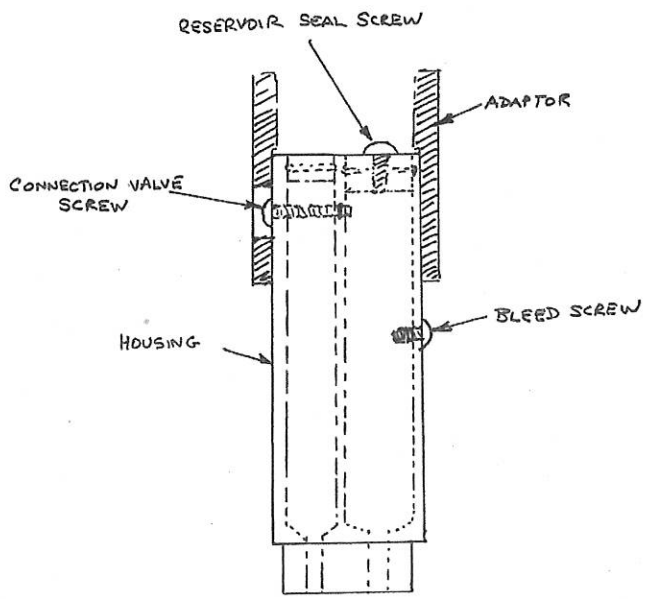


Figure 4. Details of the Multilevel type Reservoir Assembly

Installation Instructions.

The bottom sensor is usually anchored in solid ground and serves as a stable datum point to which all the other sensors are referred. This bottom sensor may be attached to a length of pipe and grouted in place, as described in Section 2.2 to 2.4, or it may be anchored to the walls of the borehole by means of a Model 1250-15 Hydraulic Bladder type borehole anchor.

The remaining intermediate sensor / reservoir combinations are anchored in the borehole by means of spring-loaded anchors which can be hydraulically or manually released when the sensor / reservoir is at its desired location.

The string of sensor / reservoir combinations can be assembled horizontally along the ground surface with the Connection Valve Screw kept closed. Make sure that the Connection Valve Screw is aligned with the hole in the Adaptor. 4600 Settlement Systems are usually shipped with the reservoir completely filled with de-aired liquid so that there is no danger of air bubbles entering the liquid tube during shipment. To put the 4600 system into service

it is necessary, now, to remove 10cc of fluid from each reservoir, as follows: First remove the Bleed Screw, (see

Figure 4 on page 8), from the side of the reservoir housing and, using the syringe supplied, remove about 10cc of fluid until the liquid level inside the reservoir is at the level of the Bleed Screw. Tilt the Housing slightly and add a few drops of light oil to the liquid surface to prevent evaporation. Now replace the Bleed Screw and tighten. It would be better if the Reservoir were not laid on its side from this point on.

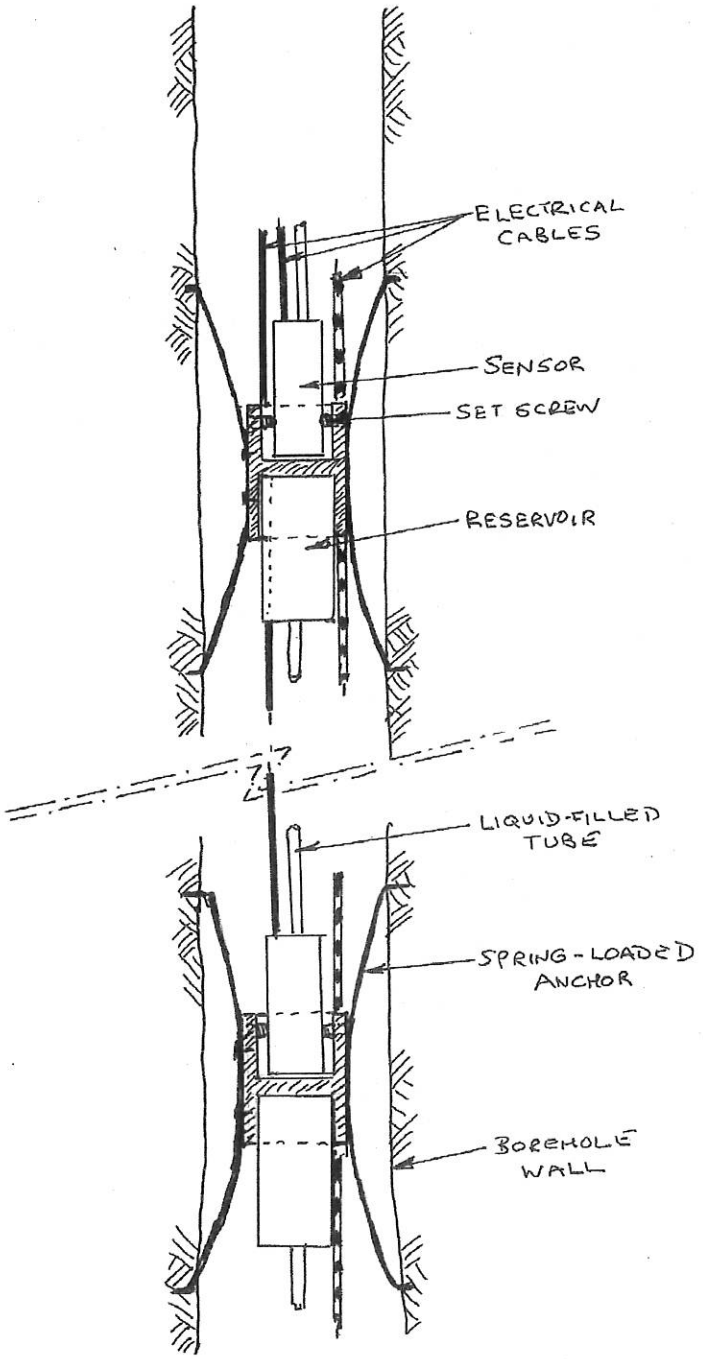
The spring-loaded anchors are tied and held in their closed position using the trip cords supplied. The hydraulically actuated cutter or the manually operated pull-pins are passed through the loops in the trip cords. A tremie pipe may be taped lightly to the lowermost sensor, or to the pipe on which it sits.

As the assembly is lowered into the borehole, each Connection Valve Screw is removed and replaced by the Seal Screw provided. Note: more than one person will be required to organize and control the various hydraulic leads/pull-cords, tubes and cables as they are lowered into the borehole. If pull-cords are used make sure that they are kept free at all times so that the anchors cannot be tripped prematurely.

The uppermost reservoir, if located at the surface, can be attached to a settlement plate, as described in Section 2.8

When all the sensors are in position, the casing can be pulled, (if the borehole is cased,) taking care not to damage or pull on the electrical cables coming from each sensor. As the casing is pulled, each spring-loaded anchor is tripped hydraulically as it clears the bottom of the casing. The borehole may be left open, or filled with a soft bentonite cement grout tremied into the borehole as the tremie pipe is retracted.

Model 4600M Assembly



Appendix C:

Specifications.

Model	4500AL[1]
Available Ranges[2] (ft) Available Ranges[2] (m)	0-10, 0-20, 0-50 3, 7, 15,
Resolution	0.025% FS
Linearity	0.5% FS[3]
Accuracy[1]	0.1% FS[4]
Over-Range	2 × FS
Thermal Coefficient	<0.05% FS/ °C
Frequency Range	1400-3500Hz

Vibrating Wire Transducer Specifications

Notes:

[1] Accuracy of test apparatus: 0.05%

[2] Other ranges available upon request.

[3] 0.1% FS linearity available upon request.

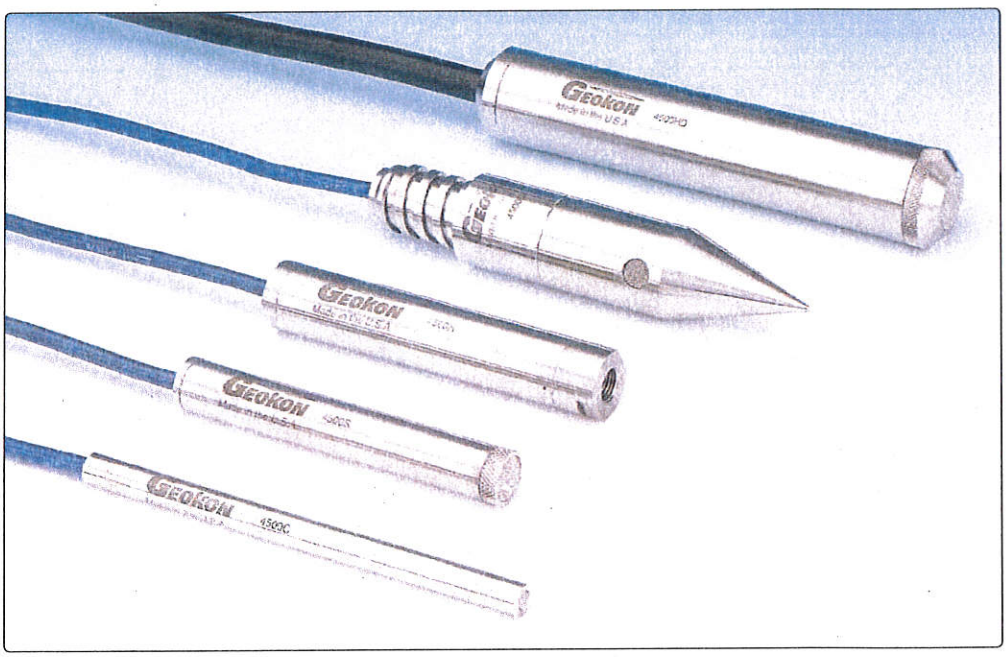
[4] Derived using 2nd order polynomial.

VW Piezometers & Pressure Transducers

Applications

For the measurement of...

- Ground water elevations
- Pore water pressures
- Pump tests
- Uplift pressures in dam foundations
- Hydraulic pressures in tanks and pipelines
- Wick drain efficiency
- Water pressures behind tunnel linings



• *Model 4500C, 4500S, 4500H, 4500DP and 4500HD Vibrating Wire Piezometers (front to back).*

Operating Principle

The transducer uses a pressure sensitive diaphragm with a vibrating wire element attached to it. The diaphragm is welded to a capsule which is evacuated and hermetically sealed. Fluid pressures acting upon the outer face of the diaphragm cause deflections of the diaphragm and changes in tension and frequency of the vibrating wire. The changing frequency is sensed and transmitted to the readout device by an electrical coil acting through the walls of the capsule.

Piezometers incorporate a porous filter stone ahead of the diaphragm, which allows the fluid to pass through but prevents soil particles from impinging directly on the diaphragm.

Advantages and Limitations

The 4500 Series Vibrating Wire Piezometers and Pressure Transducers have outstanding long-term stability and reliability, and low thermal zero shift. Cable lengths of several kilometers are no problem and the frequency output signal is not affected by changing cable resistances (caused by splicing, changes of length, terminal contact resistances, etc.), nor by penetration of moisture into the electronic circuitry.

A thermistor located in the housing permits the measurement of temperatures at the piezometer location.

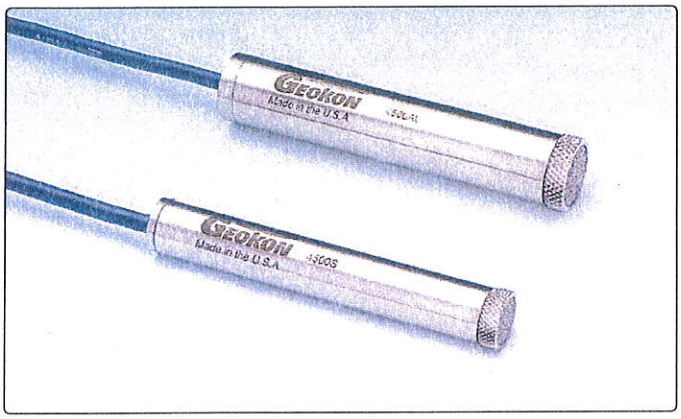
All-stainless steel or titanium construction and evacuation of the capsule guarantees a high level of corrosion resistance. Integral gas discharge tubes inside the main housing protect against lightning damage.

Standard porous filters are made from sintered 316 stainless steel. High air-entry ceramic filters are available for use in applications requiring that air be prevented from passing through the filter.

Vented versions of all models are available to provide automatic compensation for barometric pressure fluctuations. Negative pressures up to 1 Bar can be measured.

Vibrating wire pressure transducers are not suitable for the measurement of rapidly changing pressures: for these purposes Model 3400 transducers should be used.

Model 4500S/SV/SH/AL/ALV Standard Piezometers



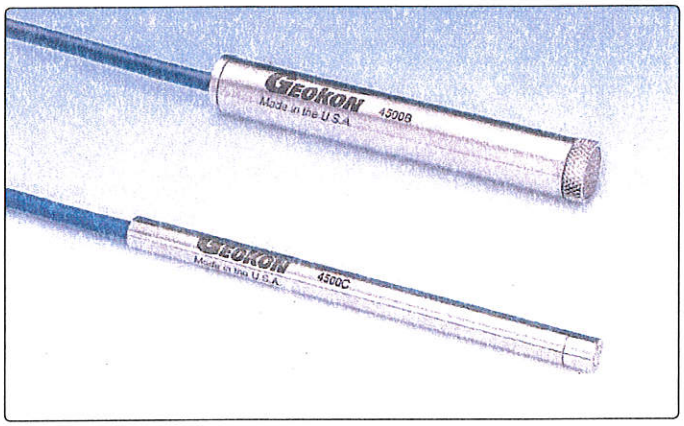
• *Model 4500S (front) and Model 4500AL (rear) Standard Piezometers.*

The Model 4500S/SV Standard Piezometer is designed to measure fluid pressures such as ground water elevations and pore pressures when buried directly in embankments, fills, etc. It is also suitable for installation inside boreholes, observation wells and standard (>19 mm diameter) piezometer riser pipe.

The Model 4500SH is designed with a heavy duty housing for pressures that exceed 3 MPa.

The Model 4500AL is designed for low-pressure ranges. The vented version (Model 4500ALV) provides automatic compensation for barometric pressure changes. Thermistors are included to measure temperatures.

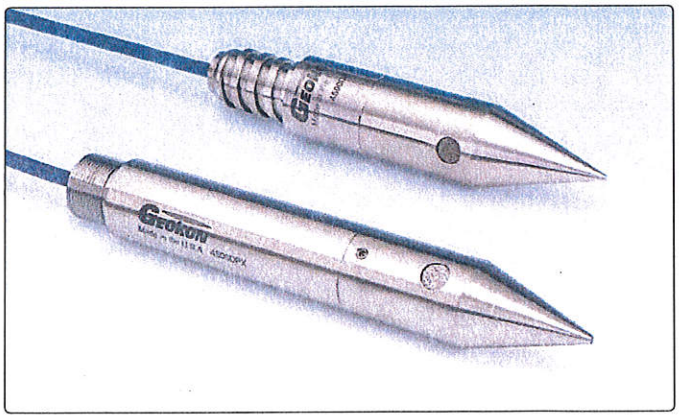
Model 4500B/BV/C Small Diameter Piezometers



• *Model 4500C (front) and Model 4500B (rear) Small Diameter Piezometers.*

These piezometers are designed to enable the automation of small diameter piezometer standpipes. The 4500B/BV fits inside 19 mm pipe and the 4500C inside 12 mm pipe.

Model 4500DP Drive Point Piezometers

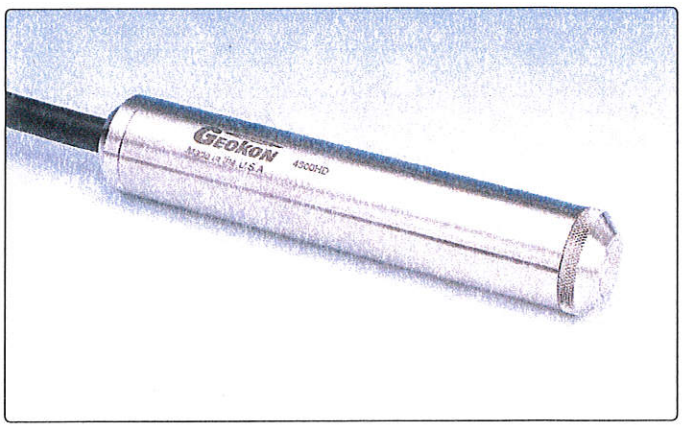


• *Model 4500DP Drive Point Piezometers.*

The Model 4500DP Drive Point Piezometer has the transducer located inside a housing with an EW drill rod thread and removable pointed nose cone. When threaded onto the end of EW drill rods, the unit can be pushed directly into soft ground with the signal cable located inside the drill rod. This model is ideally suited for use in soft clays and landfills. The piezometer may be recovered at the end of the job.

Models are also available that are similar in construction to the 4500DP but which use standard metric threads allowing for installation using cone penetrometer and other drill rods with adapters.

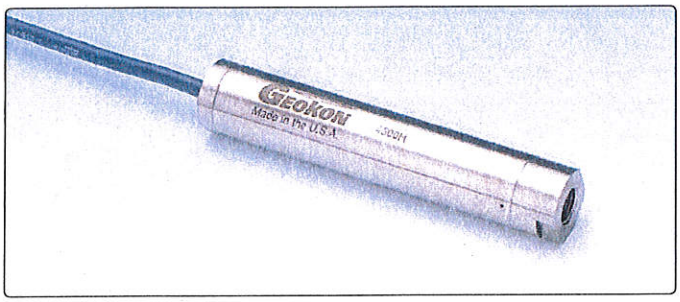
Model 4500HD Heavy Duty Piezometer



• *Model 4500HD Heavy Duty Piezometer.*

The Model 4500HD Heavy Duty Piezometer is designed for direct burial in fills and dam embankments. The 4500HD is used in conjunction with heavily armored cable to withstand earth movements during construction. Recommended for use in earth dams.

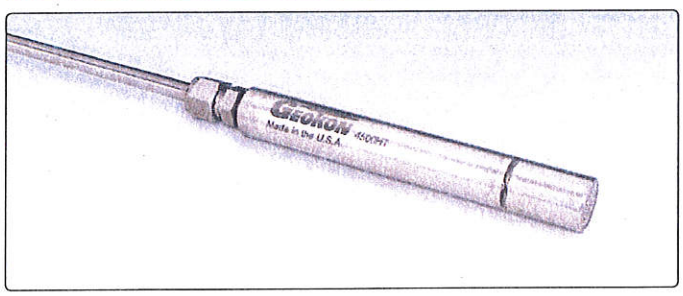
Model 4500H/HH Pressure Transducers



• *Model 4500H Pressure Transducer.*

The Model 4500H and 4500HH Pressure Transducers are supplied with a ¼-18 NPT pipe thread fitting to permit the transducer to be coupled directly into hydraulic or pneumatic pressure lines. Other pipe thread sizes are also available.

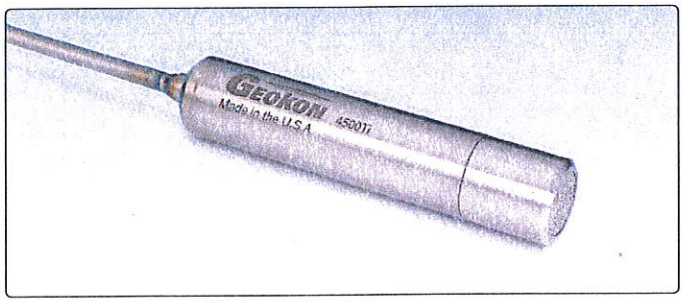
Model 4500HT High Temperature Piezometer



• *Model 4500HT High Temperature Piezometer.*

The Model 4500HT High Temperature Piezometer is designed for applications for temperatures up to 230°C. These sensors are supplied with either mineral insulated cables or Teflon cables inside stainless steel tubing. *For further details, please see the Model 4500HT data sheet.*

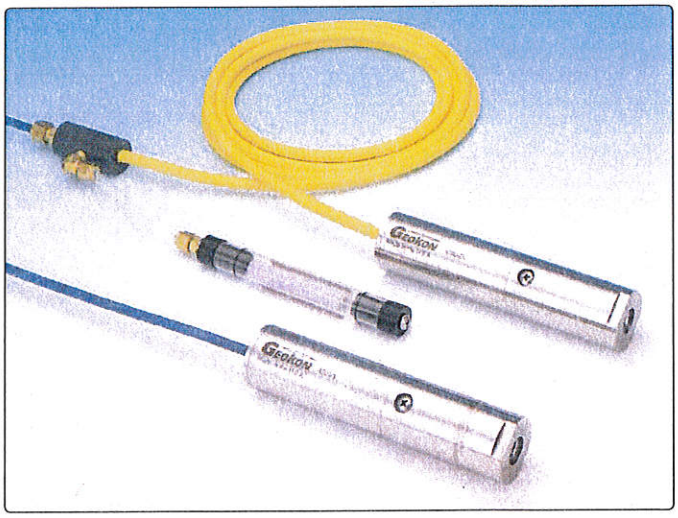
Model 4500Ti Titanium Piezometer



• *Model 4500Ti Titanium Piezometer.*

The Model 4500Ti is designed specifically for use in highly corrosive environments such as landfills and leach fields. Also used in critical areas where long term survivability is essential, for example, as in nuclear waste repositories and aggressive mine tailings. All exterior surfaces are made from titanium.

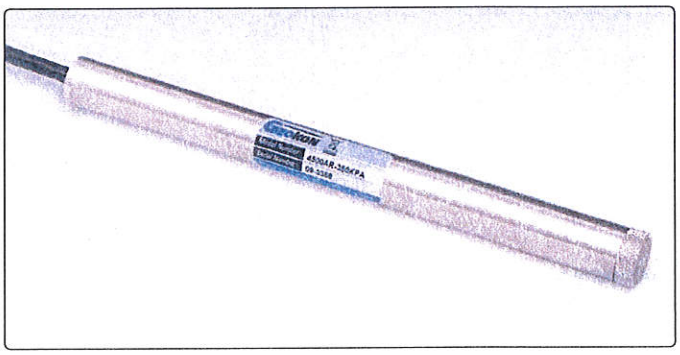
Model 4580 Pressure Transducer



• *Model 4580 Pressure Transducer.*

The Model 4580 Pressure Transducers are designed for very low fluid pressure measurements, such as groundwater elevations in wells, water levels in streams, weirs, flumes, etc. Changes in water levels of as little as 0.2 mm can be measured. Non vented types can be used as a barometer to measure atmospheric pressure changes.

Model 4500AR Autoresonant Piezometer



• *Model 4500AR "Autoresonant" Piezometer.*

The Model 4500AR "Autoresonant" Piezometer is designed for use with existing data acquisition systems incapable of reading standard (pluck and read) vibrating wire sensors. It can also be used where low frequency (< 20 Hz) dynamic measurements are required.

The Model 4500AR is powered using a 6-24 VDC supply, which yields a 5 V square wave output at the sensor frequency. This high-output offers excellent noise immunity and enhanced signal transmission over long (300 m+) cables. The Model 4500AR is available in standard pressure ranges, with corresponding resolution, linearity and accuracy.

Technical Specifications

Model	Standard Ranges	Over Range	Resolution	Accuracy	Linearity	Temperature Range[1]	Thermal Zero Shift	Diaphragm Displacement	Length × Diameter	Mass
4500S/SV	–100 to 350, 700 kPa; 1, 2, 3 MPa	2 × rated pressure	0.025% F.S.	±0.1% F.S.	< 0.5% F.S. (±0.1% F.S. optional)	–20°C to +80°C	< 0.05% F.S./°C	< 0.001 cm³ at F.S.	133 × 19.1 mm	0.12 kg
4500SH	–100 to 5, 7.5, 10, 20 MPa	2 × rated pressure	0.025% F.S.	±0.1% F.S.	< 0.5% F.S. (±0.1% F.S. optional)	–20°C to +80°C	< 0.05% F.S./°C	< 0.001 cm³ at F.S.	194 × 25.4 mm	0.44 kg
4500AL/ ALV	70, 170 kPa	2 × rated pressure	0.025% F.S.	±0.1% F.S.	< 0.5% F.S. (±0.1% F.S. optional)	–20°C to +80°C	< 0.05% F.S./°C	< 0.001 cm³ at F.S.	133 × 25.4 mm	0.25 kg
4500B/BV	–100 to 350, 700 kPa; 1, 2, 3 MPa	2 × rated pressure	0.025% F.S.	±0.1% F.S.	< 0.5% F.S. (±0.1% F.S. optional)	–20°C to +80°C	< 0.05% F.S./°C	< 0.001 cm³ at F.S.	133 × 17.5 mm	0.10 kg
4500C	–100 to 350, 700 kPa	2 × rated pressure	0.05% F.S.	±0.1% F.S.	< 0.5% F.S.	–20°C to +80°C	< 0.05% F.S./°C	< 0.001 cm³ at F.S.	165 × 11 mm	0.09 kg
4500DP	–100 to 70, 170, 350, 700 kPa; 1, 2, 3, 5, 7.5 MPa	2 × rated pressure	0.025% F.S.	±0.1% F.S.	< 0.5% F.S. (±0.1% F.S. optional)	–20°C to +80°C	< 0.05% F.S./°C	< 0.001 cm³ at F.S.	187 × 33.3 mm	0.90 kg
4500HD	–100 to 70, 170, 350, 700 kPa; 1, 2, 3, 5, 7.5 MPa	2 × rated pressure	0.025% F.S.	±0.1% F.S.	< 0.5% F.S. (±0.1% F.S. optional)	–20°C to +80°C	< 0.05% F.S./°C	< 0.001 cm³ at F.S.	203 × 38.1 mm	1.50 kg
4500H[2]	–100 to 70, 170, 350, 700 kPa; 1, 2, 3 MPa	1.5 × rated pressure	0.025% F.S.	±0.1% F.S.	< 0.5% F.S. (±0.1% F.S. optional)	–20°C to +80°C	< 0.05% F.S./°C	< 0.001 cm³ at F.S.	140 × 32 mm[3] 140 × 25.4 mm	0.30 kg
4500HH[2]	–100 to 5, 7.5, 10, 20, 35, 75, 100 MPa	1.5 × rated pressure	0.025% F.S.	±0.1% F.S.	< 0.5% F.S. (±0.1% F.S. optional)	–20°C to +80°C	< 0.05% F.S./°C	< 0.001 cm³ at F.S.	143 × 25.4 mm	0.30 kg
4500HT	–100 to 700 kPa; 1, 2, 3, 5, 7.5, 10, 25, 50, 75, 100, 150 MPa	2 × rated pressure	0.025% F.S.	±0.1% F.S.	< 0.5% F.S. (±0.1% F.S. optional)	0°C to +230°C	< 0.05% F.S./°C	< 0.001 cm³ at F.S.	133 × 19.1 mm	0.12 kg
4500Ti	–100 to 350, 700 kPa; 1, 2, 3, 5, 7.5 MPa[1]	2 × rated pressure	0.025% F.S.	±0.1% F.S.	< 0.5% F.S. (±0.1% F.S. optional)	–20°C to +80°C	< 0.05% F.S./°C	< 0.001 cm³ at F.S.	125 × 25.4 mm	0.19 kg
4580-1 (Barometer)	200 Mbar[1]	2 × rated pressure	0.025% F.S.[4]	±0.1% F.S.	< 0.5% F.S. (±0.1% F.S. optional)	–20°C to +80°C	< 0.05% F.S./°C	n/a	110 × 63.5 mm	1.18 kg
4580-2/2V	17, 35 kPa	2 × rated pressure	0.025% F.S.[4]	±0.1% F.S.	< 0.5% F.S. (±0.1% F.S. optional)	–20°C to +80°C	< 0.05% F.S./°C	n/a	165 × 38 mm	0.86 kg
4580-3V	7 kPa	2 × rated pressure	0.025% F.S.[4]	±0.1% F.S.	< 0.5% F.S.	–20°C to +80°C	< 0.05% F.S./°C	n/a	165 × 63.5 mm	1.72 kg
4500AR[5]	7, 17, 35, 70, 170, 350, 700 kPa; 1, 2, 3, 5, 7.5, 10, 20, 25, 35, 50, 75, 100, 150 MPa	2 × rated pressure	0.025% F.S.[4]	±0.1% F.S.	< 0.5% F.S. (±0.1% F.S. optional)	–20°C to +80°C	< 0.05% F.S./°C	< 0.001 cm³ at F.S.	varies according to pressure range	varies according to pressure range

Note: PSI = kPa × 0.14503, or MPa × 145.03

[1]Other ranges available on request.

[2]All high pressure sensors are potentially dangerous and care must be taken not to over-range them beyond their calibrated range. Sensors are tested to 150% of the range to provide a factor of safety.

[3]For 70 and 170 kPa range only.

[4]Depends on readout system.

[5]Power Supply Voltage Range: 6 V (min), 12 V (nom), 24 V (max). Power Supply Current: 15.5 mA @ 12 V @ 20°C. Operating Temperature Range: 0° to +70°C.

VW Output Signal Voltage: 5 V square wave @ fundamental vibrating wire frequency. VW Output Signal Impedance: 50 ohms. Cable: 3 twisted pairs.

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The World Leader in Vibrating Wire Technology™

Geokon maintains an ongoing policy of design review and reserves the right to amend products and specifications without notice.

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Instruction Manual

Model 4500

series

Vibrating Wire Piezometers

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1. THEORY OF OPERATION

Geokon Model 4500 Vibrating Wire Piezometers are intended primarily for long-term measurements of fluid and/or pore pressures in standpipes, boreholes, embankments, pipelines and pressure vessels. Several models of the 4500 series are available (see Appendix A). Contact Geokon sales engineers for specific application information.

The instrument utilizes a sensitive stainless steel diaphragm to which a vibrating wire element is connected. See Figure 1-1. In use, changing pressures on the diaphragm cause it to deflect, and this deflection is measured as a change in tension and frequency of vibration of the vibrating wire element. The square of the vibration frequency is directly proportional to the pressure applied to the diaphragm. Two coils, one with a magnet, another with a pole piece, are located close to the wire. In use, a pulse of varying frequency (swept frequency) is applied to the coils and this causes the wire to vibrate primarily at its resonant frequency. When excitation ends the wire continues to vibrate and a sinusoidal AC electrical signal, at the resonant frequency, is induced in the coils and transmitted to the readout box where it is conditioned and displayed.

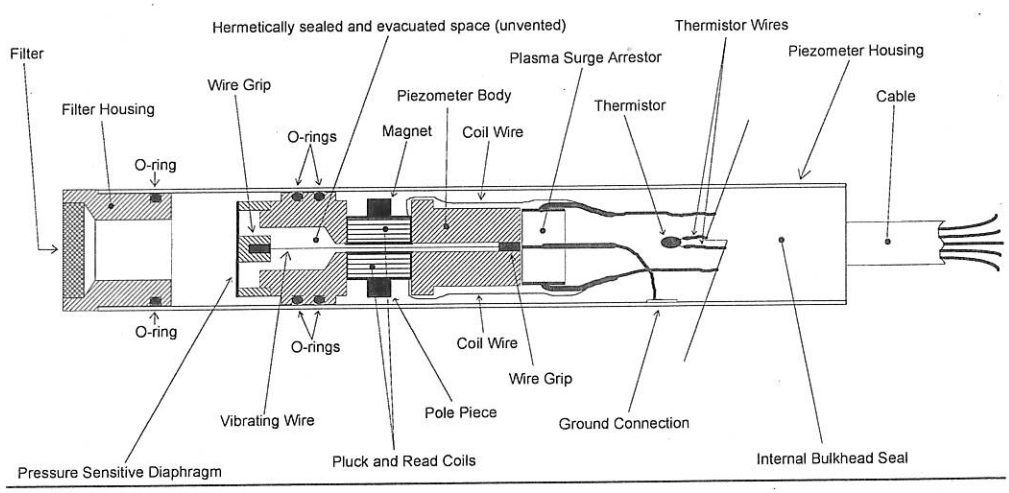

Figure 1-1 Vibrating Wire Piezometer

To prevent damage to the sensitive diaphragm a filter is used to keep out solid particles. Figure 1-1 illustrates. Standard filters are 50 micron stainless steel; high air entry value tips are available on request.

All exposed components are made of corrosion resistant stainless steel and, if proper installation techniques are used, the device should have an unlimited life. In salt water it may be necessary to use special materials for the diaphragm and housing.

Portable readout units are available to provide the excitation, signal conditioning and readout of the instrument. Datalogging systems are also available for remote unattended data collection of multiple sensors. Contact Geokon for additional information.

Calibration data are supplied with each piezometer for conversion of gage readings to engineering units such as pressure or level. See Section 4.

2. INSTALLATION

(For Quick Installation Instructions see AppendixE)

2.1 Preliminary Tests

Upon receipt of the piezometer the zero reading should be checked and noted (see Sections 3.1 to 3.3 for readout instructions). A thermistor is included inside the body of the piezometer (Figure 1-1) for the measurement of temperature (see Section 3.4 for instructions).

Calibration data are supplied with each gage and a zero reading, at a specific temperature and barometric pressure, is included. Zero readings at the site should coincide with the calibration zero readings within +/- 50 digits after barometric and temperature corrections are made. The factory elevation is +580 ft. Before March 21, 1995 factory barometric pressure readings were corrected to sea level; readings after this date represent absolute pressure. (Barometric pressure changes with elevation at a rate of ≈½ psi per 1,000 ft.) See Figure 2-1 for a sample calibration sheet.

GEOKON 48 Spencer St. Lebanon, NH 03766 USA

Vibrating Wire Pressure Transducer Calibration Report

Model Number: 4500INS-700 kPa

Serial Number: 1043811

Date of Calibration: September 14, 2011

Temperature: 21.7 °C

Barometric Pressure: 994.7 mbar

Technician: [illegible]

Applied Pressure (kPa)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Pressure (Linear)	Error Linear (%FS)	Calculated Pressure (Polynomial)	Error Polynomial (%FS)
0.0	9073	9074	9074	1.526	0.22	0.028	0.00
140.0	8303	8304	8304	139.7	-0.04	140.0	-0.01
280.0	7528	7528	7528	278.9	-0.15	280.0	0.00
420.0	6748	6749	6749	418.8	-0.16	420.0	-0.01
560.0	5963	5963	5963	559.8	-0.02	560.1	0.01
700.0	5174	5174	5174	701.5	0.21	700.0	-0.01

(kPa) Linear Gage Factor (G): -0.1795 (kPa/ digit)

Regression Zero: 9082

Polynomial Gage factors: A: -7.113E-07 B: -0.1694 C: _____

Thermal Factor (K): 0.1319 (kPa/ °C)

Calculate C by setting P=0 and R_1 = initial field zero reading into the polynomial equation

(psi) Linear Gage Factor (G): -0.02603 (psi/ digit)

Polynomial Gage Factors: A: -1.032E-07 B: -0.02456 C: _____

Thermal Factor (K): 0.01913 (psi/ °C)

Calculate C by setting P=0 and R_1 = initial field zero reading into the polynomial equation

Calculated Pressures:

Linear, $P = G(R_1 - R_0) + K(T_1 - T_0) - (S_1 - S_0)^*$

Polynomial, $P = AR_1^2 + BR_1 + C + K(T_1 - T_0) - (S_1 - S_0)^*$

*Barometric pressures expressed in kPa or psi. Barometric compensation is not required with vented transducers.

The above instrument was found to be in tolerance in all operating ranges.
The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1.

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Figure 2-1 Sample Calibration Sheet

2.1.1 Establishing an Initial Zero Reading

Vibrating Wire Piezometers differ from other types of pressure sensors in that they indicate a reading at zero pressure. **Therefore it is imperative that an accurate initial zero pressure reading be obtained for each piezometer as this reading will be used in all subsequent data reduction.**

There are different ways of doing this but the essential element in all methods is that the piezometer be allowed to thermally stabilize in a constant temperature environment while the pressure on the piezometer is barometric only. Because of the way the piezometer is constructed it takes about 5 to 15 minutes for the temperature of all the different elements to equalize.

It will be necessary to measure the barometric pressure only if the piezometer is un-vented and if it will be installed in a location that is subject to barometric pressure changes that require correction, such as in an open well. *A piezometer sealed in place at depth could be recording pressures in groundwater that is not hydraulically connected to the atmosphere, and, for which, barometric pressure compensation would be inappropriate.*

The recommended way to achieve temperature stability is to hang the piezometer in the borehole at a point just above the water and wait until the piezometer reading has stopped changing. Now take the zero reading and read the temperature, indicated by the thermistor inside the piezometer.

Another way is to place the piezometer under water in a bucket and allow 5 to 15 minutes for the temperature to stabilize, then lift the piezometer out of the water and immediately take a reading. When doing this, lift the piezometer by the cable only, do not handle the piezometer housing as body heat from the hand could cause temperature transients. Use the thermistor inside the piezometer to measure the water temperature.

Another way is to simply read the piezometer while in the air while making sure that the temperature has had time to stabilized. If this method is chosen be sure that the piezometer is protected from sunlight or sudden changes of temperature: Wrapping it in some insulating material is recommended.

Yet another way is to lower the piezometer to a known depth as marked out on the piezometer cable, (The diaphragm inside the piezometer is located approximately ¾ inch (15mm), from the tip. Then use a dip meter to accurately measure the depth to the water surface. Now, after temperature stabilization, read the piezometer pressure and, using the factory calibration constants and a knowledge of the pressure (height x density) of the water column above the piezometer, calculate either the equivalent zero pressure reading, if the linear regression is used, or the factor, C, if the second order polynomial is used.

A question may arise as to what to do with the filter stone while taking zero readings. If a standard stainless steel filter is being used, it will not matter if the filter stone is saturated or not. But if ceramic high air entry filter stone is in use then it must be saturated while taking the zero readings and must not be allowed to dry out to the extent that surface tension effects can affect the zero reading.

Caution. – do not allow the piezometer to freeze once it has been filled with water.

2.1.2 Checking the Calibration

The following procedure is recommended to verify the calibration factor as supplied on the calibration sheet (Figure 2-1). It should be borne in mind that the piezometer measures water pressure and that the conversion to a water level requires an accurate knowledge of the density of the water.

1. The best method is to remove the filter housing and filter stone from off the tip of the piezometer: Pulling on the knurled ring will accomplish this. Alternatively, saturate the filter stone and fill the space between it and the diaphragm with water (Section 2.6).

2. Lower the piezometer to a point near the bottom of a water-filled borehole, or below the surface of a body of water. The use of a dip meter to measure the actual depth of the water in the borehole will be very desirable.

3. Allow 15-20 minutes for the piezometer to come to thermal equilibrium. Using a readout box record the reading at that level.

4. Raise the piezometer by known depth increments. Record the pressure reading at each depth increment. Calculate the in-situ calibration factor and compare to the calibration factor on the calibration sheet. The two values should agree within ± 0.5%. Repeat test if necessary.

There are a couple of things that can affect the in-situ calibration:

- The density of the in-situ water may not be 1gm/cc if it is saline or turbid. If this is the case then the factory calibration factor, should be adjusted to take into account the actual water density.
- **The water level inside the borehole may vary during the test due to the displacement of the water level as the cable is raised and lowered in the borehole.** This effect will be greater where the borehole diameter is smaller. For example, a Model 4500S-50 piezometer lowered 50 feet below the water column in a 1 inch (.875 inch ID) standpipe will displace the water level by more than 4 feet! If a dip-meter is available it should be used to confirm the water levels at each depth increment.

2.2 Installation in Standpipes or Wells

- A zero reading is first established (follow the procedures outlined in Section 2.1.1). The filter stone is saturated (follow the procedures in Section 2.6). Make a mark on the cable which will lie opposite the top of the standpipe, (well), when the piezometer has reached the desired depth. (The piezo diaphragm lies ¾ inch above the tip of the piezo).

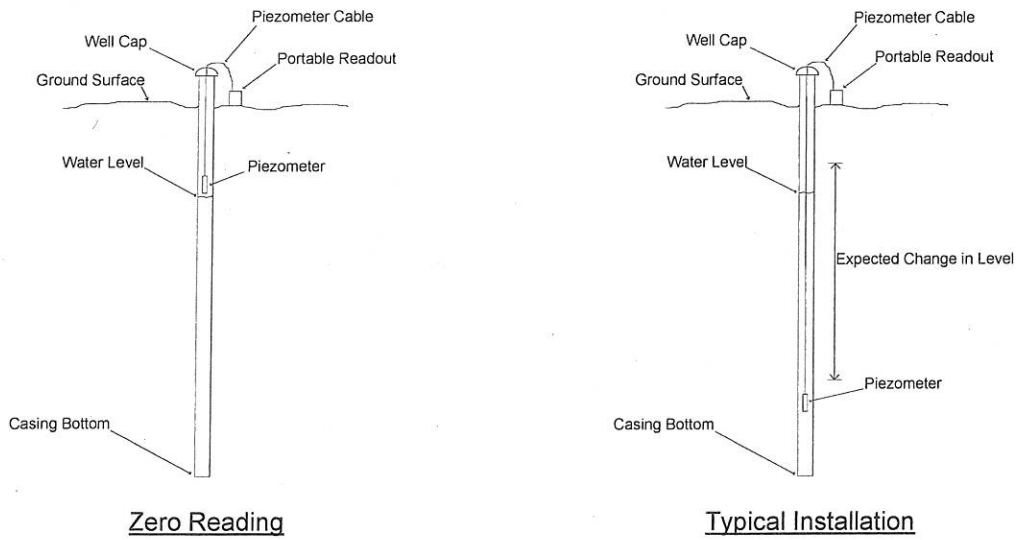


Figure 2-2 Typical Level Monitoring Installations

Be sure the cable is securely fastened at the top of the well or readings could be in error due to slippage of the piezometer into the well.

It is not recommended that piezometers be installed in wells or standpipes where an electrical pump and/or cable is present or nearby. Electrical interference from these sources can cause unstable readings. If unavoidable, it is recommended that the piezometer be placed inside a piece of steel pipe.

In situations where packers are used in standpipes the same sequence as above should be noted and special care should be taken to avoid cutting the cable jacket with the packer since this could introduce a possible pressure leakage path.

2.3 Installation in Boreholes

Geokon piezometers can be installed in boreholes in either single or multiple installations per hole, in cased or uncased holes. See Figure 2-3. Careful attention must be paid to borehole sealing techniques if pore pressures in a particular zone are to be monitored.

Boreholes should be drilled either without drilling mud or with a material that degrades rapidly with time, such as Revert™. The hole should extend from 6 inches to 12 inches below the proposed piezometer location and should be washed clean of drill cuttings. The bottom of the borehole should then be backfilled with clean fine sand to a point 6 inches below the piezometer tip. The piezometer can then be lowered, as delivered, into position. Preferably, the piezometer may be encapsulated in a canvas-cloth bag

containing clean, saturated sand and then lowered into position. While holding the instrument in position (a mark on the cable is helpful) clean sand should be placed around the piezometer and to a point 6 inches above it. Figure 2-3 details two methods of isolating the zone to be monitored.

Installation A

Immediately above the "collection zone" the borehole should be sealed with either alternating layers of bentonite and sand backfill tamped in place for approximately 1 foot followed by common backfill or by an impermeable bentonite-cement grout mix. If multiple piezometers are to be used in a single hole the bentonite-sand plugs should be tamped in place below and above the upper piezometers and also at intervals between the piezometer zones. When designing and using tamping tools special care should be taken to ensure that the piezometer cable jackets are not cut during installation.

Installation B

Immediately above the "collection zone" the borehole should be filled with an impermeable bentonite grout.

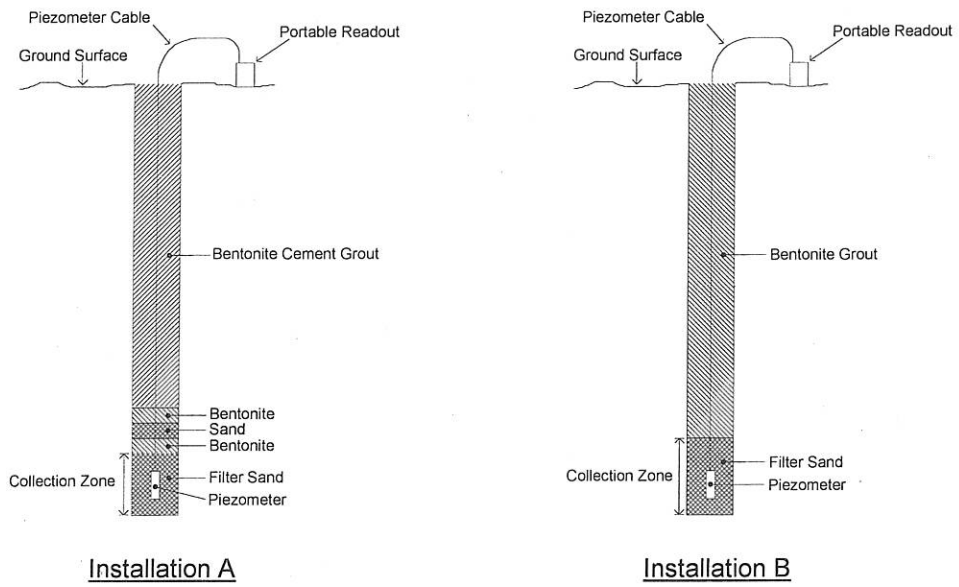


Figure 2-3 Typical Borehole Installations

Installation C

It should be noted that since the vibrating wire piezometer is basically a no-flow instrument, collection zones of appreciable size are not required and the piezometer can, in fact, be placed directly in contact with most materials provided that the fines are not able to migrate through the filter. The latest thinking, (*Mikkelson and Green, Piezometers in Fully Grouted Boreholes.Proceedings of FMGM 2003, Field Measurements in Geomechanics, Oslo, Norway, Sept. 2003. Contact Geokon for a copy of this paper)*

is that it is not necessary to provide sand zones and that the piezometer can be grouted directly into the borehole using a bentonite cement grout only.
The general rule for installing piezometers in this way is to use a bentonite grout that mimics the strength of the surrounding soil. The emphasis should be on controlling the water-cement ratio. This is accomplished **by mixing the cement with the water first.** The most effective way of mixing is in a 50 to 200 gallon barrel or tub using the drill-rig pump to circulate the mix. Any kind of bentonite powder used to make drilling mud, combined with Type 1 or 2 Portland cement can be used. The exact amount of bentonite added will vary somewhat. The table below shows 2 possible mixes for strengths of 50 psi and 4 psi.
Add the measured amount of clean water to the barrel then gradually add the cement in the correct weight ratio. Next add the bentonite powder, slowly, so clumps do not form. Keep adding bentonite until the watery mix turns to an oily/slimy consistency. Let the grout thicken for another five to ten minutes. Add more bentonite as required until it is a smooth thick cream like pancake batter. It is now as heavy as it is feasible to pump.
When pumping grout, unless the tremie-pipe is to be left in place, withdraw the tremie-pipe after each batch, by an amount corresponding to the grout level in the borehole.
Caution: if the grout is pumped into the hole, rather than tremied, there is a danger that the piezometer will be over-ranged and damaged., So pumping direct into the bottom of the borehole should be avoided. It is good practice to read the piezometer while pumping.

Application	**Grout for Medium to Hard Soils**		**Grout for Soft Soils**	
Materials	Weight	Ratio by Weight	Weight	Ratio by Weight
Water	30 gallons	2.5	75 gallons	6.6
Portland Cement	94 lbs (1 sack)	1	94 lbs (1 sack)	1
Bentonite	25 lbs (as required)	0.3	39 lbs (as required)	0.4
Notes	The 28 day compressive strength of this mix is about 50 psi, similar to very stiff to hard clay. The modulus is about 10,000 psi		The 28 day strength of this mix is about 4psi, similar to very soft clay.	

Table 1 showing Cement/bentonite/water ratios for two grout mixes.

(For more details on this method of installation ask for a copy of the FMGM paper)

2.4 Installation in Fills and Embankments

Geokon piezometers are normally supplied with direct burial cable suitable for placement in fills such as highway embankments and dams, both in the core and in the surrounding materials.

In installations in non-cohesive fill materials the piezometer may be placed directly in the fill or, if large aggregate sizes are present, in a saturated sand pocket in the fill. If installed in large aggregate, additional measures may be necessary to protect the cable from damage.

In fills such as impervious dam cores where sub-atmospheric pore water pressure may need to be measured (as opposed to the pore air pressure) a ceramic tip with a high air entry value is often used which should be carefully placed in direct contact with the compacted fill material (see Installation A of Figure 2-4). In partially saturated fills if only the pore air pressure is to be measured, the standard tip is satisfactory. It should be noted that the coarse tip measures the air pressure when there is a difference between the pore air pressure and the pore water pressure, and that the difference between the two pressures is due to the capillary suction in the soil. The general consensus is that the difference is normally of no consequence to embankment stability. As a general rule the coarse (low air entry) tip is suitable for most routine measurements and, in fine cohesive soils, sand pockets should not be used around the piezometer tip (see Installation B of Figure 2-4). In high traffic areas and in material which exhibit pronounced "weaving", a heavy-duty armored cable should be used.

Cables are normally installed inside shallow trenches with the fill material consisting of smaller size aggregate. This fill is carefully hand compacted around the cable. Bentonite plugs are placed at regular intervals to prevent migration of water along the cable path.

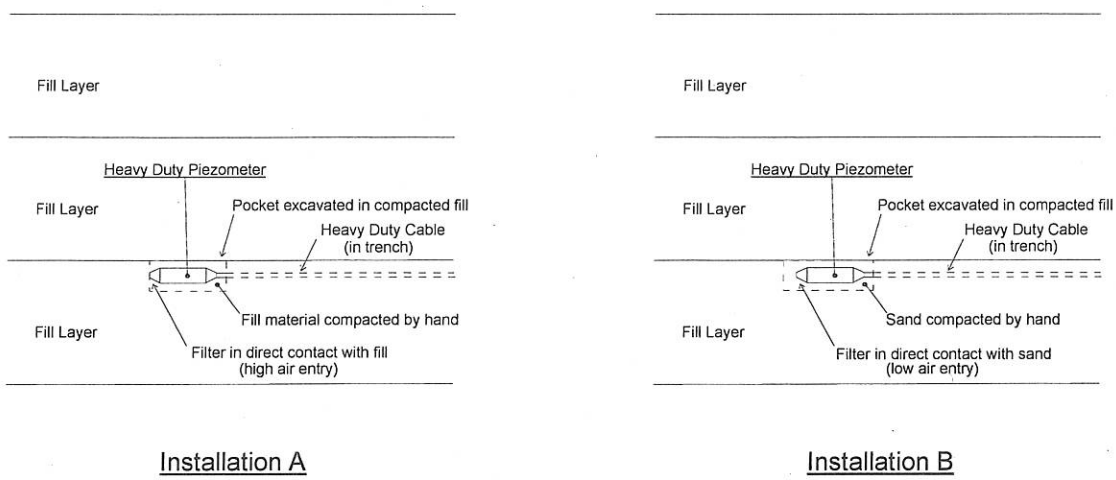


Figure 2-4 Typical Dam Installations

2.5 Installation by Pushing or Driving into Soft Soils

The Model 4500DP piezometer is designed for pushing into soft soils. See Figure 2-5. The unit is connected directly to the drill rod (AW, EW or other) and pressed into the ground either by hand or by means of the hydraulics on the rig. The units can also be driven but the possibility of a zero shift due to the driving forces exists.

The piezometer should be connected to the readout box and monitored during the driving process. If measurement pressures reach or exceed the calibrated range, the driving should be stopped and the pressures allowed to dissipate before continuing.

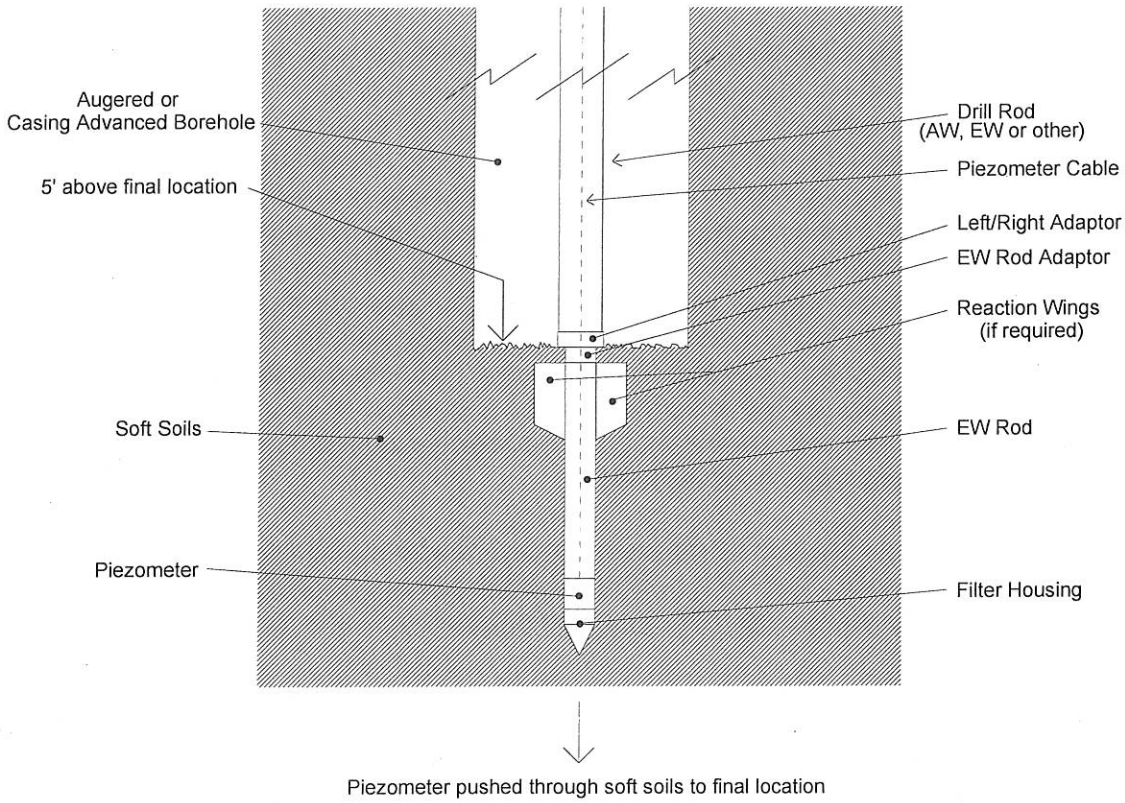


Figure 2-5 Typical Soft Soils Installation

The drill rod can be left in place or it can be removed. If it is to be removed then a special 5 foot section of EW (or AW) rod with wings and a left hand thread are attached directly to the piezometer tip. This section is detached from the rest of the drill string by rotating the string clockwise. The left hand thread will then loosen. The wings prevent the special EW rod from turning. A special LH/RH adapter is available from Geokon. The adapter is retrieved along with the drill string.

2.6 De-airing Filter Tips

Caution. – do not allow the piezometer to freeze once it has been filled with water. Most Geokon filter tips can be removed for saturating and re-assembly. The procedures are as follows:

2.6.1 Low Air Entry Filter, Model 4500S and 4500PN

For accurate results, total saturation of the filter is necessary. For the low air entry filter normally supplied, this saturation occurs as the tip is lowered into the water. Water is forced into the filter, compressing the air in the space between the filter stone and the pressure sensitive diaphragm. After a period of time, this air will dissolve into the water until the space and the filter is entirely filled with water. To speed up the saturation process, remove the filter assembly and fill the space above the diaphragm with water, then slowly replace the filter housing allowing the water to squeeze through the filter stone. With low pressure range piezometers (<10 psi) take readings with a readout box while pushing the filter housing on so as not to over-range the sensor.

To maintain saturation, the unit should be kept under water until installation.

If the 4500S piezometer is to be used in standpipes and raised and lowered many times the filter may loosen. A permanent filter assembly may be required. The removable filter may be fixed permanently by prick punching the piezometer tube approximately 1/16" to 1/8" behind the filter assembly joint.

Screens are also available for standpipe installations. Screens are less likely than standard filters to become clogged where salts in the water can be deposited if the filter is allowed to dry out completely.

2.6.2 Removable Ceramic Filter, Model 4500S

The ceramic filter on the 4500S piezometer is also removable for de-airing. Because of the high air entry characteristics, de-airing is particularly important for this filter assembly. Filters with different air entry values require different procedures.

1 Bar Filters

1. Remove the filter from the piezometer by carefully twisting and pulling on the filter housing assembly.

2. Boil the filter assembly in de-aired water.

3. Re-assemble the filter housing and piezometer under the surface of a container of de-aired water. Be sure that no air is trapped in the transducer cavity. While pushing the filter on use a readout box to monitor the diaphragm pressure. Allow over-range pressure to dissipate before pushing further.

4. To maintain saturation, the unit should remain immersed until installation.

2 Bar and Higher

The proper procedure for de-airing and saturating these filters is somewhat complex and should be done either at the factory by Geokon or by carefully following the instructions below:

1. Place the assembled piezometer, filter down, in a vacuum chamber with an inlet port at the bottom for de-aired water.

2. Close off the water inlet and evacuate the chamber. The transducer should be monitored while the chamber is being evacuated.

3. When the maximum vacuum has been achieved, allow de-aired water to enter the chamber and reach an elevation a few inches above the piezometer filter.

4. Close off the inlet port. Release the vacuum.

5. Observe the transducer output. It will take as long as 24 hours for the filter to completely saturate (5 bar) and the pressure to rise to zero.

6. After saturation the transducer should be kept in a container of de-aired water until installation. If de-aired at the factory a special cap is applied to the piezometer to maintain saturation.

2.6.3 Model 4500DP

The 4500 Drive Point is de-aired in the same way as the above models by first unscrewing the point of the piezometer assembly and then following the instruction for the 4500S.

2.7 Model 4500H Transducer

When connecting the Model 4500H transducer to external fittings, the fitting should be tightened into the ¼"-NPT thread with a wrench on the flats provided on the transducer housing. Also, avoid tightening onto a closed system since the process of tightening the fittings could over-range and permanently damage the transducer. If in doubt, attach the gage leads to the readout box and take readings while tightening. Teflon tape on the threads makes for easier and more positive connection to the transducer.
CAUTION: All high pressure sensors are potentially dangerous and care must be taken not to over-range them beyond their calibrated range. Sensors are tested to 150% of the range to provide a factor of safety.

2.8 Splicing and Junction Boxes

Because the vibrating wire output signal is a frequency rather than current or voltage, variations in cable resistance have little effect on gage readings and, therefore, splicing of cables has no effect either and, in some cases, may be beneficial. For example, if multiple piezometers are installed in a borehole, and the distance from the borehole to the terminal box or datalogger is great, a splice (or junction box, see Figure 2-6) could be made to connect the individual cables to a single multi-conductor cable. This multi-conductor cable would then be run to the readout station. For such installations it is recommended that the piezometer be supplied with enough cable to reach the installation depth plus extra cable to pass through drilling equipment (rods, casing, etc.).
The cable used for making splices should be a high quality twisted pair type with 100% shielding (with integral shield drain wire). When splicing, it is very important that the shield drain wires be spliced together! Splice kits recommended by Geokon incorporate casts placed around the splice then filled with epoxy to waterproof the connections. When properly made, this type of splice is equal or superior to the cable itself in strength and electrical properties. Contact Geokon for splicing materials and additional cable splicing instructions

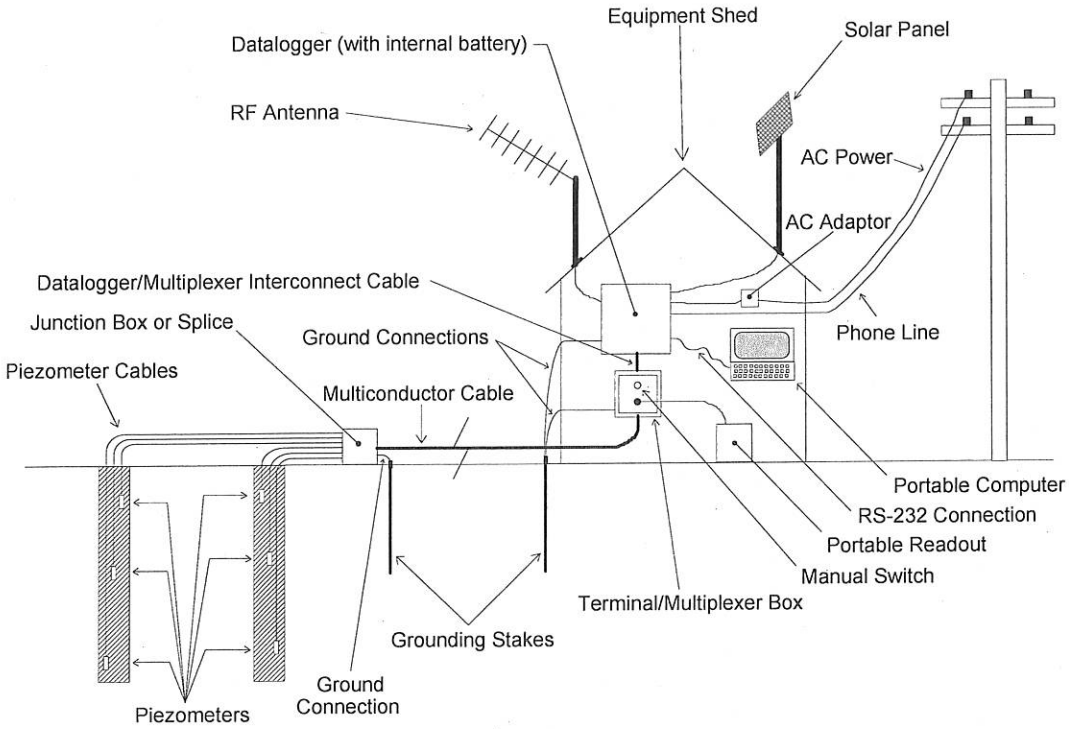


Figure 2-6 Typical Multi-Piezometer Installation

Junction boxes and terminal boxes are available from Geokon for all types of applications. In addition, portable readout equipment and datalogging hardware are available. See Figure 2-6. Contact Geokon for specific application information.

2.9 Lightning Protection

In exposed locations it is vital that the piezometer be protected against lightning strikes.

A tripolar plasma surge arrestor (Figure 1-1) is built into the body of the piezometer and protects against voltage spikes across the input leads. Following are additional lightning protection measures available;

1. If the instruments will be read manually with a portable readout (no terminal box) a simple way to help protect against lightning damage is to connect the cable leads to a good earth ground when not in use. This will help shunt transients induced in the cable to ground thereby protecting the instrument.

2. Terminal boxes available from Geokon can be ordered with lightning protection built in. There are two levels of protection;

   - The terminal board used to make the gage connections has provision for installation of plasma surge arrestors (similar to the device inside the piezometer).

- Lightning Arrestor Boards (LAB-3) can be incorporated into the terminal box. These units utilize surge arrestors and transzorbs to further protect the piezometer.

In the above cases the terminal box would be connected to an earth ground.

3. Improved protection using the LAB-3 can be had by placing the board in line with the cable as close as possible to the installed piezometer (see Figure 2-7). This is the recommended method of lightning protection.

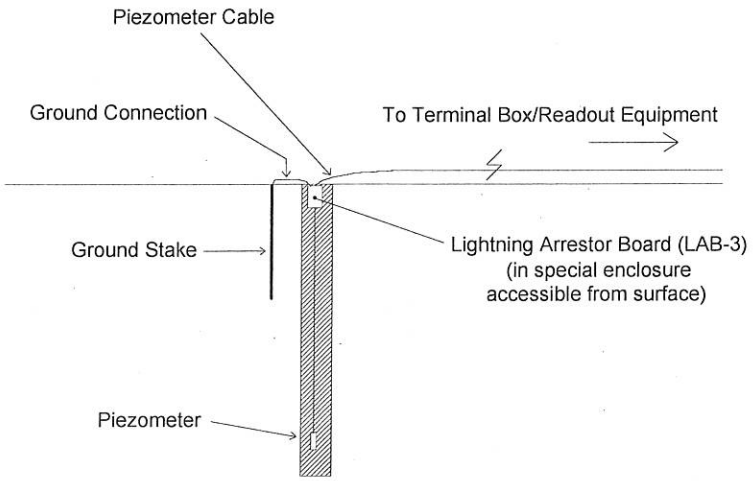


Figure 2-7 Recommended Lightning Protection Scheme

3. TAKING READINGS

3.1 Operation of the GK-403 Readout Box

The GK-403 can store gage readings and also apply calibration factors to convert readings to engineering units. Consult the GK-403 Instruction Manual for additional information on Mode "G" of the Readout. The following instructions will explain taking gage measurements using Modes "B" and "F" (similar to the GK-401 switch positions "B" and "F").

Connect the Readout using the flying leads or in the case of a terminal station, with a connector. The red and black clips are for the vibrating wire gage, the white and green leads are for the thermistor and the blue for the shield drain wire.

1. Turn the display selector to position "B" (or "F"). Readout is in digits (Equation 4-1).

2. Turn the unit on and a reading will appear in the front display window. The last digit may change one or two digits while reading. Press the "Store" button to record the value displayed. If the no reading displays or the reading is unstable see section 5 for troubleshooting suggestions. The thermistor will be read and output directly in degrees centigrade.

3. The unit will automatically turn itself off after approximately 2 minutes to conserve power.

3.2 Operation of the GK-404 Readout Box

The GK404 is a palm sized readout box which displays the Vibrating wire value and the temperature in degrees centigrade.
The GK-404 Vibrating Wire Readout arrives with a patch cord for connecting to the vibrating wire gages. One end will consist of a 5-pin plug for connecting to the respective socket on the bottom of the GK-404 enclosure. The other end will consist of 5 leads terminated with alligator clips. Note the colors of the alligator clips are red, black, green, white and blue. The colors represent the positive vibrating wire gage lead (red), negative vibrating wire gage lead (black), positive thermistor lead (green), negative thermistor lead (white) and transducer cable drain wire (blue). The clips should be connected to their respectively colored leads from the vibrating wire gage cable.

Use the **POS** (Position) button to select position **B** and the MODE button to select **Dg** (digits).
Other functions can be selected as described in the GK404 Manual.

The GK-404 will continue to take measurements and display the readings until the OFF button is pushed, or if enabled, when the automatic Power-Off timer shuts the GK-404 off.
The GK-404 continuously monitors the status of the (2) 1.5V AA cells, and when their combined voltage drops to 2V, the message **Batteries Low** is displayed on the screen. A fresh set of 1.5V AA batteries should be installed at this point

3.4 Measuring Temperatures

Each vibrating wire piezometer is equipped with a thermistor for reading temperature. The thermistor gives a varying resistance output as the temperature changes. Usually the white and green leads are connected to the internal thermistor. High temperature versions use a different thermistor than the standard versions.
The GK-403 and GK 404 readout boxes when used with the **standard** temperature thermistor will display the temperature in °C automatically. They will **not** do this with high temperature thermistors. The GK 401 readout box will not read temperatures directly, instead an ohmmeter must be used.

1. Connect the ohmmeter to the two thermistor leads coming from the piezometer. (Since the resistance changes with temperature are so large, the effect of cable resistance is usually insignificant. For long cables a correction can be applied – equal to 16 ohms per thousand feet.)

2. For standard temperature models, look up the temperature for the measured resistance in Table B-1.Page 21 Alternately the temperature could be calculated

using Equation B-1. For high temperature models use Table B2 or the equation B2 given on page 22.

4. DATA REDUCTION

4.1 Pressure Calculation

The digits displayed by the Geokon Models GK-403 or GK-404 Readout Boxes on channel B are based on the equation

$$\text{Digits} = \left(\frac{1}{\text{Period}}\right)^2 \times 10^{-3} \quad \text{or} \quad \text{Digits} = \frac{\text{Hz}^2}{1000}$$

Equation 4-1 Digits Calculation

For example, a piezometer reading 8000 digits corresponds to a period of 354μs and a frequency of 2828 Hz. Note that in the above equation, the period is in seconds: the readout boxes display microseconds.
Since digits are directly proportional to the applied pressure,

Pressure = (Current Reading - Initial Reading) × Linear Calibration Factor

or

$$P = (R_1 - R_0) \times G$$

Equation 4-2 Convert Digits to Pressure

Since the linearity of most sensors is within □ 0.2% FS the errors associated with non-linearity are of minor consequence. However, for those situations requiring the highest accuracy it may be desirable to use a second order polynomial to get a better fit of the data points. The use of a second order polynomial is explained in Appendix D.

The calibration sheet, a typical example of which is shown in figure 2.1 on page 4, shows the data from which the linear gage factor and the second order polynomial coefficients are derived. Columns on the right show the size of the error incurred by assuming a linear coefficient and the improvement which can be expected by going to a second order polynomial . In many cases the difference is minor. The calibration sheets gives the pressure in certain engineering units. These can be converted to other engineering units using the multiplication factors shown in Table 4-1 below.

From → To ↓	psi	"H_2O	'H_2O	mm H_20	m H_20	"HG	mm HG	atm	mbar	bar	kPa	MPa
psi	1	.036127	.43275	.0014223	1.4223	.49116	.019337	14.696	.014503	14.5039	.14503	145.03
"H_2O	27.730	1	12	.039372	39.372	13.596	.53525	406.78	.40147	401.47	4.0147	4016.1
'H_2O	2.3108	.08333	1	.003281	3.281	1.133	.044604	33.8983	.033456	33.4558	.3346	334.6
mm H_20	704.32	25.399	304.788	1	1000	345.32	13.595	10332	10.197	10197	101.97	101970
m H_20	.70432	.025399	.304788	.001	1	.34532	.013595	10.332	.010197	10.197	.10197	101.97
"HG	2.036	.073552	.882624	.0028959	2.8959	1	.03937	29.920	.029529	29.529	.2953	295.3
mm HG	51.706	1.8683	22.4196	.073558	73.558	25.4	1	760	.75008	750.08	7.5008	7500.8
atm	.06805	.0024583	.0294996	.0000968	.0968	.03342	.0013158	1	.0009869	.98692	.009869	9.869
mbar	68.947	2.4908	29.8896	.098068	98.068	33.863	1.3332	1013.2	1	1000	10	10000
bar	.068947	.0024908	.0298896	.0000981	.098068	.033863	.001333	1.0132	.001	1	.01	10
kPa	6.8947	.24908	2.98896	.0098068	9.8068	3.3863	.13332	101.320	.1	100	1	1000
MPa	.006895	.000249	.002988	.00000981	.009807	.003386	.000133	.101320	.0001	.1	.001	1

Table 4-1 Engineering Units Multiplication Factors

Note: Due to changes in specific gravity with temperature the factors for mercury and water in the above table are approximations!

4.2 Temperature Correction

Careful selection of materials is made in constructing the vibrating wire piezometer to minimize thermal effects, however, most units still have a slight temperature coefficient. Consult the supplied calibration sheet to obtain the coefficient for a given piezometer.

Since piezometers are normally installed in a tranquil and constant temperature environment, corrections are not normally required. If however, that is not the case for a selected installation, corrections can be made using the internal thermistor (Figure 1-1) for temperature measurement. See Section 3.4 for instructions regarding obtaining the piezometer temperature.

Temperature correction equation is as follows;

Temperature Correction = (Current Temperature - Initial Temperature) × Thermal Factor

or

$$P_T = (T_1 - T_0) \times K$$

Equation 4-3 Temperature Correction

The calculated correction would then be **added** to the Pressure calculated using Equation 4-2. If the engineering units were converted remember to apply the same conversion to the calculated temperature correction!

For example, assume the initial temperature was 22° C, the current temperature is 15° C, and the thermal coefficient is +0,1319 kPa per °C rise (Figure 2-1). The temperature correction is +0.1319(15-22) = -0.92 kPa.

4.3 Barometric Correction (required only on un-vented transducers)

Since the standard piezometer is hermetically sealed and un-vented, it responds to changes in atmospheric pressure. That being the case, corrections may be necessary, particularly for the sensitive, low pressure models. For example, a barometric pressure change from 29 to 31 inches of mercury would result in ≈1 PSI of error (or ≈2.3 feet if monitoring water level in a well!). Thus it is advisable to read and record the barometric pressure every time the piezometer is read. A separate pressure transducer (piezometer), kept out of the water, may be used for this purpose.
Barometric correction equation is as follows;

Barometric Correction = (Current Barometer - Initial Barometer) × Conversion Factor

or

$$P_B = (S_1 - S_0) \times F$$

Equation 4-4 Barometric Correction

Since barometric pressure is usually recorded in inches of mercury a Conversion Factor is necessary to convert to PSI. The Conversion Factor for inches of mercury to PSI is .491. Table 4-1 lists other common Conversion Factors.

The calculated correction is usually **subtracted** from the Pressure calculated using Equation 4-2. If the engineering units were converted remember to apply the same conversion to the calculated barometric correction!

The user should be cautioned that this correction scheme assumes ideal conditions. In reality, conditions are not always ideal. For example, if the well is sealed, barometric effects at the piezometer level may be minimal or attenuated from the actual changes at the surface. Thus errors may result when applying a correction which is not required. We recommend, in these cases, to independently record barometric pressure changes and correlate these with observed pressure changes to arrive at a correction factor.

> An alternative to making barometric correction is to use piezometers that are vented to the atmosphere as noted section 4.3.1. However, vented piezos only make sense if the piezo is in an open well or standpipe and the user is only interested in the water level. Otherwise, if the piezo is buried it is not certain that the full effect of the barometric change will be felt immediately at the piezo and is more likely to be attenuated and delayed, in which case a vented piezo would automatically apply a correction that is too large and too soon. Having an on-site barometer with un-vented piezos also has the advantage that you can see the barometric change and judge to what extent it may have affected the piezo reading.

Equation 4-5 describes the pressure calculation with temperature and barometric correction applied.

$$P_{corrected} = ((R_1 - R_0)\times G) + ((T_1 - T_0) \times K) - ((S_1 - S_0) \times F)$$

Equation 4-5 Corrected Pressure Calculation

4.3.1 Vented Piezometers

Vented piezometers are designed to eliminate barometric effects. The space inside the transducer is not hermetically sealed and evacuated (see Figure 1-1), but is connected via a tube (integral with the cable) to the atmosphere. A chamber containing desiccant capsules is attached to the end of the tube to prevent moisture from entered the transducer cavity. Vented piezometers require more maintenance then non-vented types, and there is always a danger that water can find its way into the inside of the transducer and ruin it. As supplied, the outer end of the desiccant chamber is closed by means of a seal screw to keep the desiccant fresh during storage and transportation. **THE SEAL SCREW MUST BE REMOVED BEFORE THE PIEZOMETER IS PUT INTO SERVICE!** The desiccant capsules are blue when fresh, they will gradually turn pink as they absorb moisture. When they have turned light pink in color they should be replaced. Contact Geokon for replacement capsules.

4.4 Environmental Factors

Since the purpose of the piezometer installation is to monitor site conditions, factors which may affect these conditions should always be observed and recorded. Seemingly minor effects may have a real influence on the behavior of the structure being monitored and may give an early indication of potential problems. Some of the factors include, but

are not limited to; blasting, rainfall, tidal levels, excavation and fill levels and sequences, traffic, temperature and barometric changes (and other weather conditions), changes in personnel, nearby construction activities, seasonal changes, etc.

5. TROUBLESHOOTING

Maintenance and troubleshooting of vibrating wire piezometers is confined to periodic checks of cable connections and maintenance of terminals. The transducers themselves are sealed and not user serviceable. Following are typical problems and suggested remedial action.

- **Piezometer fails to give a reading**

1. Check the resistance of the coils by connecting an ohmmeter across the gage terminals. Nominal resistance is 180Ω (±5%), plus cable resistance at approximately 16Ω per 1000' of 22 AWG wire. If the resistance is very high or infinite the cable is probably broken or cut. If the resistance is very low the gage conductors may be shorted. If a cut or a short is located in the cable, splice according to instructions in Section 2.8.
2. Check the readout with another gage.
3. The Piezometer may have been over-ranged or shocked. Inspect the diaphragm and housing for damage. Contact the factory.

- **Piezometer reading unstable**

1. Connect the shield drain wire to the readout using the green (GK-401) or the blue (GK-403) clip.
2. Isolate the readout from the ground by placing it on a piece of wood or similar non-conductive material.
3. Check for sources of nearby noise such as motors, generators, antennas or electrical cables. Move the piezometer cables if possible. Contact the factory for filtering and shielding equipment available.
4. The Piezometer may have been damaged by over-ranging or shock.
5. The body of the Piezometer may be shorted to the shield. Check the resistance between the shield drain wire and the Piezometer housing.

- **Thermistor resistance is too high**

1. Likely there is an open circuit. Check all connections, terminals and plugs. If a cut is located in the cable, splice according to instructions in Section 2.8.

- **Thermistor resistance is too low**

1. Likely there is a short. Check all connections, terminals and plugs. If a short is located in the cable, splice according to instructions in Section 2.8.
2. Water may have penetrated the interior of the piezometer. There is no remedial action.

APPENDIX A - SPECIFICATIONS

Model	4500S	4500AL[1]	4500AR	4500B	4500C	4500DP	4580[2]
Available Ranges (psi)	0-50 0-100 0-150 0-250 0-500 0-750 0-1000 0-1500 0-3000 0-5000 0-10000 0-15000	0-5 0-10 0-25		0-50 0-100 0-250	0-50 0-100 0-250	0-10 0-25 0-50 0-150 0-250 0-500 0-750 0-1000 0-1500 0-3000 0-5000 0-10000	0-1 0-5
Resolution	0.025% FS	0.025% FS	0.025% FS	0.025% FS	0.05% FS	0.025% FS	0.01% FS
Linearity	< 0.5% FS[3]	< 0.5% FS[3]	< 0.5% FS[3]	< 0.5% FS[3]	< 0.5% FS[3]	< 0.5% FS[3]	< 0.5% FS[3]
Accuracy	0.1% FS[4]	0.1% FS[4]	0.1% FS[4]	0.1% FS[4]	0.1% FS[4]	0.1% FS[4]	0.1% FS
Over-Range	2 × FS	2 × FS	2 × FS	2 × FS	2 × FS	2 × FS	2 × FS
Thermal Coefficient	<0.025% FS/ °C	<0.05% FS/ °C	<0.05% FS/ °C	<0.025% FS/ °C	<0.05% FS/ °C	<0.025% FS/ °C	<0.025% FS/ °C
Temperature Range	-20°C to +80°C	-20°C to +80°C	-20°C to +80°C	-20°C to +80°C	-20°C to +80°C	-20°C to +80°C	-20°C to +80°C
OD	.75" 19.05 mm	1" 25.40 mm	.75" 19.05 mm	.687" 17.45 mm	.437" 11.10 mm	1.3" 33.3mm	1.5" 38.10 mm
Length	5.25" 133 mm	5.25" 133 mm	10" 254 mm	5.25" 133 mm	6.5" 165 mm	7.36" 187 mm	6.5" 165 mm

Table A-1 Vibrating Wire Piezometer Specifications

Accuracy of Geokon test apparatus: 0.1%

Contact Geokon for specific application information.

Notes:

[1] Accuracy of test apparatus: 0.05%

[2] Other ranges available upon request.

[3] 0.1% FS linearity available upon request.

[4] Derived using 2nd order polynomial.

APPENDIX B – STANDARD TEMPERATURE THERMISTOR TEMPERATURE DERIVATION

Thermistor Type: YSI 44005, Dale #1C3001-B3, Alpha #13A3001-B3

Resistance to Temperature Equation B1:

$$T = \frac{1}{A + B(LnR) + C(LnR)^3} - 273.2$$

Where; T = Temperature in °C.
LnR = Natural Log of Thermistor Resistance
$A = 1.4051 \times 10^{-3}$ (coefficients calculated over the –50 to +150° C. span)
$B = 2.369 \times 10^{-4}$
$C = 1.019 \times 10^{-7}$

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
201.1K	-50	16.60K	-10	2417	+30	525.4	+70	153.2	+110
187.3K	-49	15.72K	-9	2317	31	507.8	71	149.0	111
174.5K	-48	14.90K	-8	2221	32	490.9	72	145.0	112
162.7K	-47	14.12K	-7	2130	33	474.7	73	141.1	113
151.7K	-46	13.39K	-6	2042	34	459.0	74	137.2	114
141.6K	-45	12.70K	-5	1959	35	444.0	75	133.6	115
132.2K	-44	12.05K	-4	1880	36	429.5	76	130.0	116
123.5K	-43	11.44K	-3	1805	37	415.6	77	126.5	117
115.4K	-42	10.86K	-2	1733	38	402.2	78	123.2	118
107.9K	-41	10.31K	-1	1664	39	389.3	79	119.9	119
101.0K	-40	9796	0	1598	40	376.9	80	116.8	120
94.48K	-39	9310	+1	1535	41	364.9	81	113.8	121
88.46K	-38	8851	2	1475	42	353.4	82	110.8	122
82.87K	-37	8417	3	1418	43	342.2	83	107.9	123
77.66K	-36	8006	4	1363	44	331.5	84	105.2	124
72.81K	-35	7618	5	1310	45	321.2	85	102.5	125
68.30K	-34	7252	6	1260	46	311.3	86	99.9	126
64.09K	-33	6905	7	1212	47	301.7	87	97.3	127
60.17K	-32	6576	8	1167	48	292.4	88	94.9	128
56.51K	-31	6265	9	1123	49	283.5	89	92.5	129
53.10K	-30	5971	10	1081	50	274.9	90	90.2	130
49.91K	-29	5692	11	1040	51	266.6	91	87.9	131
46.94K	-28	5427	12	1002	52	258.6	92	85.7	132
44.16K	-27	5177	13	965.0	53	250.9	93	83.6	133
41.56K	-26	4939	14	929.6	54	243.4	94	81.6	134
39.13K	-25	4714	15	895.8	55	236.2	95	79.6	135
36.86K	-24	4500	16	863.3	56	229.3	96	77.6	136
34.73K	-23	4297	17	832.2	57	222.6	97	75.8	137
32.74K	-22	4105	18	802.3	58	216.1	98	73.9	138
30.87K	-21	3922	19	773.7	59	209.8	99	72.2	139
29.13K	-20	3748	20	746.3	60	203.8	100	70.4	140
27.49K	-19	3583	21	719.9	61	197.9	101	68.8	141
25.95K	-18	3426	22	694.7	62	192.2	102	67.1	142
24.51K	-17	3277	23	670.4	63	186.8	103	65.5	143
23.16K	-16	3135	24	647.1	64	181.5	104	64.0	144
21.89K	-15	**3000**	**25**	624.7	65	176.4	105	62.5	145
20.70K	-14	2872	26	603.3	66	171.4	106	61.1	146
19.58K	-13	2750	27	582.6	67	166.7	107	59.6	147
18.52K	-12	2633	28	562.8	68	162.0	108	58.3	148
17.53K	-11	2523	29	543.7	69	157.6	109	56.8	149
								55.6	150

Table B-1 **STANDARD TEMPERATURE** Thermistor Resistance versus Temperature

High Temperature Thermistor Linearization using SteinHart-Hart Log Equation

Thermistor Type: Thermometrics BR55KA822J

Basic Equation B2:

$$T = \frac{1}{A + B(LnR) + C(LnR)^3} - 273.2$$

Where: T = Temperature in °C.
LnR = Natural Log of Thermistor Resistance
$A = 1.02569 \times 10^{-3}$
$B = 2.478265 \times 10^{-4}$
$C = 1.289498 \times 10^{-7}$

Note: Coefficients calculated over -30° to +260° C. span.

Table B2

Temp	R (ohms)	LnR	LnR^3	Calculated Temp	Diff	FS Error	Temp	R (ohms)	LnR	LnR^3	Calculated Temp	Diff	FS Error
-30	113898	11.643	1578.342	-30.17	0.17	0.06	120	407.62	6.010	217.118	120.00	0.00	0.00
-25	86182	11.364	1467.637	-25.14	0.14	0.05	125	360.8	5.888	204.162	125.00	0.00	0.00
-20	65805	11.094	1365.581	-20.12	0.12	0.04	130	320.21	5.769	191.998	130.00	0.00	0.00
-15	50684.2	10.833	1271.425	-15.10	0.10	0.03	135	284.95	5.652	180.584	135.00	0.00	0.00
-10	39360	10.581	1184.457	-10.08	0.08	0.03	140	254.2	5.538	169.859	140.01	-0.01	0.00
-5	30807.4	10.336	1104.068	-5.07	0.07	0.02	145	227.3	5.426	159.773	145.02	-0.02	-0.01
0	24288.4	10.098	1029.614	-0.05	0.05	0.02	150	203.77	5.317	150.314	150.03	-0.03	-0.01
5	19294.6	9.868	960.798	4.96	0.04	0.01	155	183.11	5.210	141.428	155.04	-0.04	-0.01
10	15424.2	9.644	896.871	9.98	0.02	0.01	160	164.9	5.105	133.068	160.06	-0.06	-0.02
15	12423	9.427	837.843	14.98	0.02	0.01	165	148.83	5.003	125.210	165.08	-0.08	-0.03
20	10061.4	9.216	782.875	19.99	0.01	0.00	170	134.64	4.903	117.837	170.09	-0.09	-0.03
25	8200	9.012	731.893	25.00	0.00	0.00	175	122.1	4.805	110.927	175.08	-0.08	-0.03
30	6721.54	8.813	684.514	30.01	-0.01	0.00	180	110.95	4.709	104.426	180.07	-0.07	-0.02
35	5540.74	8.620	640.478	35.01	-0.01	0.00	185	100.94	4.615	98.261	185.10	-0.10	-0.04
40	4592	8.432	599.519	40.02	-0.02	-0.01	190	92.086	4.523	92.512	190.09	-0.09	-0.03
45	3825.3	8.249	561.392	45.02	-0.02	-0.01	195	84.214	4.433	87.136	195.05	-0.05	-0.02
50	3202.92	8.072	525.913	50.01	-0.01	-0.01	200	77.088	4.345	82.026	200.05	-0.05	-0.02
55	2693.7	7.899	492.790	55.02	-0.02	-0.01	205	70.717	4.259	77.237	205.02	-0.02	-0.01
60	2276.32	7.730	461.946	60.02	-0.02	-0.01	210	64.985	4.174	72.729	210.00	0.00	0.00
65	1931.92	7.566	433.157	65.02	-0.02	-0.01	215	59.819	4.091	68.484	214.97	0.03	0.01
70	1646.56	7.406	406.283	70.02	-0.02	-0.01	220	55.161	4.010	64.494	219.93	0.07	0.02
75	1409.58	7.251	381.243	75.01	-0.01	0.00	225	50.955	3.931	60.742	224.88	0.12	0.04
80	1211.14	7.099	357.808	80.00	0.00	0.00	230	47.142	3.853	57.207	229.82	0.18	0.06
85	1044.68	6.951	335.915	85.00	0.00	0.00	235	43.673	3.777	53.870	234.77	0.23	0.08
90	903.64	6.806	315.325	90.02	-0.02	-0.01	240	40.533	3.702	50.740	239.69	0.31	0.11
95	785.15	6.666	296.191	95.01	-0.01	0.00	245	37.671	3.629	47.788	244.62	0.38	0.13
100	684.37	6.528	278.253	100.00	0.00	0.00	250	35.055	3.557	45.001	249.54	0.46	0.16
105	598.44	6.394	261.447	105.00	0.00	0.00	255	32.677	3.487	42.387	254.44	0.56	0.19
110	524.96	6.263	245.705	110.00	0.00	0.00	260	30.496	3.418	39.917	259.34	0.66	0.23
115	461.91	6.135	230.952	115.00	0.00	0.00							

Table B2 High Temperature. Temperature v Thermistor Resistance

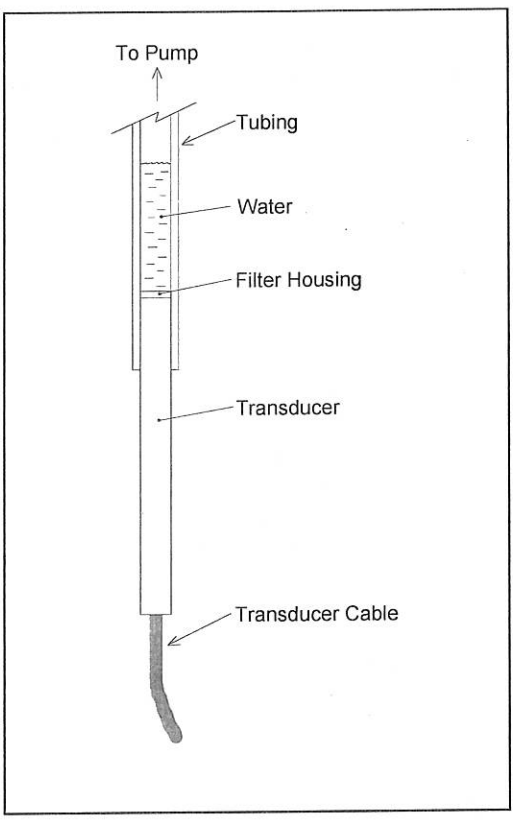
APPENDIX C - NOTES REGARDING THE MODEL 4500C

Installation

The construction of this very slender vibrating wire transducer, requires a miniaturization of the internal parts and consequently they are somewhat delicate. Despite every precaution it is possible for the zero to shift during shipment due to rough handling. However, tests have shown that the zero may shift but the calibration factors do not change. Therefore it is doubly important that the initial no load zero reading be taken prior to installation. **And it is also important to handle the transducer gently during the installation procedure.**

If the pressures to be measured are less than 5 psi the filter stone in the filter housing must be saturated. ***However, the filter stone and housing are not removable in the 4500C. Any attempt to remove the filter stone or the housing will destroy the transducer!***

To saturate the filter a hand vacuum pump and short length of tubing (½" surgical tubing) is required. Attach the tube to the transducer as shown in the figure. Fill the tubing with approximately 2" (5 cm) of water. Hold the transducer so that the water rests on the filter. Attach the other end of the tube to the hand vacuum pump. While holding the transducer so that the water rests on the filter (and doesn't enter the pump!), squeeze the hand pump to initiate vacuum in the tubing. This will draw the air out of the filter and the space behind it. The water will replace it. A vacuum of 20-25" Hg. (50-65 cm Hg.) is sufficient for proper evacuation.



A hand pump that has been used successfully is the mityvacII® by Neward Enterprises, Inc. of Cucamonga, CA, USA. Hand pumps and tubing are available from the factory.

Data Reduction

Data reduction follows the same procedures as outlined in Section 4 of this manual.. Use Table 4-1 to convert psi to other engineering units.

APPENDIX D - NON LINEARITY AND THE USE OF A SECOND ORDER POLYNOMIAL TO IMPROVE THE ACCURACY OF THE CALCULATED PRESSURE

Most vibrating wire pressure transducers are sufficiently linear (± 0.2 % FS) that use of the linear calibration factor satisfies normal requirements. However, it should be noted that the accuracy of the calibration data, which is dictated by the accuracy of the calibration apparatus, is always ± 0.1 % FS.

This level of accuracy can be recaptured, even where the transducer is non-linear, by the use of a second order polynomial expression which gives a better fit to the data then does a straight line. The polynomial expression has the form:

$$\text{pressure} = AR^2 + BR + C$$

where R is the reading (digits channel B) and A,B,C, are coefficients. The figure E1 on page 25 shows a typical calibration sheet of a transducer which has a fairly normal non-linearity. The figure under the "Linearity (%FS)" column is

$$\frac{\text{Calculated pressure- True pressure}}{\text{Full-scale Pressure}} \times 100\% = \frac{G(R_1 - R_0) - P}{F.S} \times 100\%$$

Note The linearity is calculated using the regression zero for R_0 shown on the sheet.

For example when P= 420 kPa, G $(R_1 - R_0)$ = - 0.1795(6749-9082), gives a calculated pressure of 418.8 kPa. The error is 1.2 kPa equal to 122mm of water.

Whereas the polynomial expression gives a calculated pressure of A $(6749)^2$ + B (6749) + 1595.7 = 420.02 kPa and the actual error is only 0.02 kPa or 2mm of water.

Note. If the polynomial equation is used it is important that the value of C, in the polynomial equation, be taken in the field, following the procedures described in section 2.1.1. The field value of C is calculated by inserting the initial field zero reading into the polynomial equation with the pressure, P, set to zero.

If the field zero reading is not available calculate C using the zero pressure reading on the calibration sheet. (not the regression zero) In the above example the value of C would be derived from the equation $0 = A(9074)^2 + B(9074)$ from which C = 1595.7

It should be noted that where changes of water levels are being monitored it makes little difference whether the linear coefficient or the polynomial expression is used.

GEOKON 48 Spencer St. Lebanon, NH 03766 USA

Vibrating Wire Pressure Transducer Calibration Report

Model Number: 4500INS-700 kPa

Date of Calibration: September 14, 2011

Serial Number: 1043811

Temperature: 21.7 °C

Barometric Pressure: 994.7 mbar

Technician: Stuart Kenny

Applied Pressure (kPa)	Gage Reading 1st Cycle	Gage Reading 2nd Cycle	Average Gage Reading	Calculated Pressure (Linear)	Error Linear (%FS)	Calculated Pressure (Polynomial)	Error Polynomial (%FS)
0.0	9073	9074	9074	1.526	0.22	0.028	0.00
140.0	8303	8304	8304	139.7	-0.04	140.0	-0.01
280.0	7528	7528	7528	278.9	-0.15	280.0	0.00
420.0	6748	6749	6749	418.8	-0.16	420.0	-0.01
560.0	5963	5963	5963	559.8	-0.02	560.1	0.01
700.0	5174	5174	5174	701.5	0.21	700.0	-0.01

(kPa) Linear Gage Factor (G): -0.1795 (kPa/ digit)

Regression Zero: 9082

Polynomial Gage factors: A: -7.113E-07 B: -0.1694 C: _____

Thermal Factor (K): 0.1319 (kPa/ °C)

Calculate C by setting P=0 and R_1 = initial field zero reading into the polynomial equation

(psi) Linear Gage Factor (G): -0.02603 (psi/ digit)

Polynomial Gage Factors: A: -1.032E-07 B: -0.02456 C: _____

Thermal Factor (K): 0.01913 (psi/ °C)

Calculate C by setting P=0 and R_1 = initial field zero reading into the polynomial equation

Calculated Pressures:

Linear, $P = G(R_1 - R_0) + K(T_1 - T_0) - (S_1 - S_0)^*$

Polynomial, $P = AR_1^2 + BR_1 + C + K(T_1 - T_0) - (S_1 - S_0)^*$

*Barometric pressures expressed in kPa or psi. Barometric compensation is not required with vented transducers.

The above instrument was found to be in tolerance in all operating ranges.
The above named instrument has been calibrated by comparison with standards traceable to the NIST, in compliance with ANSI Z540-1

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Figure E1 - Vibrating Wire Pressure Transducer Calibration Sheet

APPENDIX E - QUICK INSTRUCTIONS FOR INSTALLING A VIBRATING WIRE PIEZOMETER.

- Take a zero reading at zero, (atmospheric), pressure. Make sure that the temperature has not changed for 15 minutes previously. (Or until the piezo reading has stabilized). Check that this zero reading is compatible with the zero on the calibration sheet

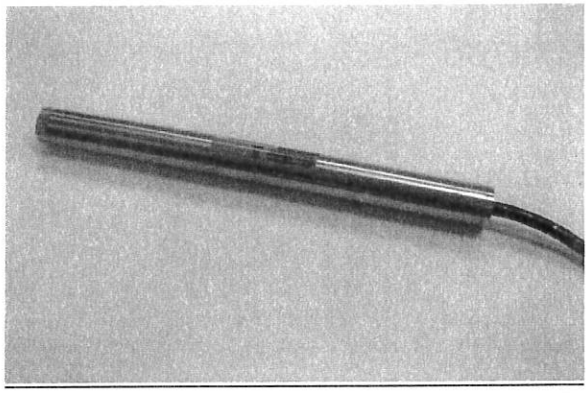
- Record the barometric pressure and the temperature at the time the zero reading is taken.

- Carefully measure the length of the cable and make a mark on the cable which will lie opposite the top of the borehole, well, or standpipe when the piezometer has reached the desired depth. (The piezo diaphragm lies ¾ inch above the tip of the piezo).

- Saturate the piezometer filter. (Section 2.6)

- Follow the instruction of Section 2.2 for installation in standpipes or wells or Section 2.3 for boreholes.

APPENDIX F - Model 4500AR piezometer



The Model 4500 AR piezometer is designed to be used with readouts systems that can read frequency but do not have the capability to "pluck' the VW gage. This sensor has built-in electronics that cause the gage wire to vibrate in a continuous mode at its resonant frequency. The output from the sensor is a 5 volt DC square wave at this frequency.
A DC input voltage in the range of 6- 24 volts is required to operate the gage. The current consumption is approximately 21 mA at 12VDC. The gage output is independent of the input voltage. Multiple sensors powered simultaneously can be read at quite fast rates, up to 5 sensors per second and dynamic measurements on a single sensor can be made up to about 20Hz.
The gage is installed in the field in the same way that the Model 4500 standard piezometer is installed. (See Section 2)

Piezometer Wiring: The 3-pair cable is wired in pairs with each pair comprising one colored and one black lead.

Red	**+6-24 VDC Power**
Red's black	**Ground**
White	**Output**
White's black	**Output Ground**
Green	**Thermistor +**
Green's black	**Thermistor –**
Bare	**Shield**

Upon power up the gage will immediately start to "ring" at the resonant frequency and will continue to do so until the power is removed. Continuous operation will have no effect on the gage life.
Note
The sensor comprises two transducers, the VW pressure sensor and a thermistor for measuring temperature. The signals from the VW transducer are high level frequency and will interfere with the thermistor output if left powered during the period that the thermistor is being read. If the temperature reading is important the power to the pressure sensor should be switched off while the reading is taken.

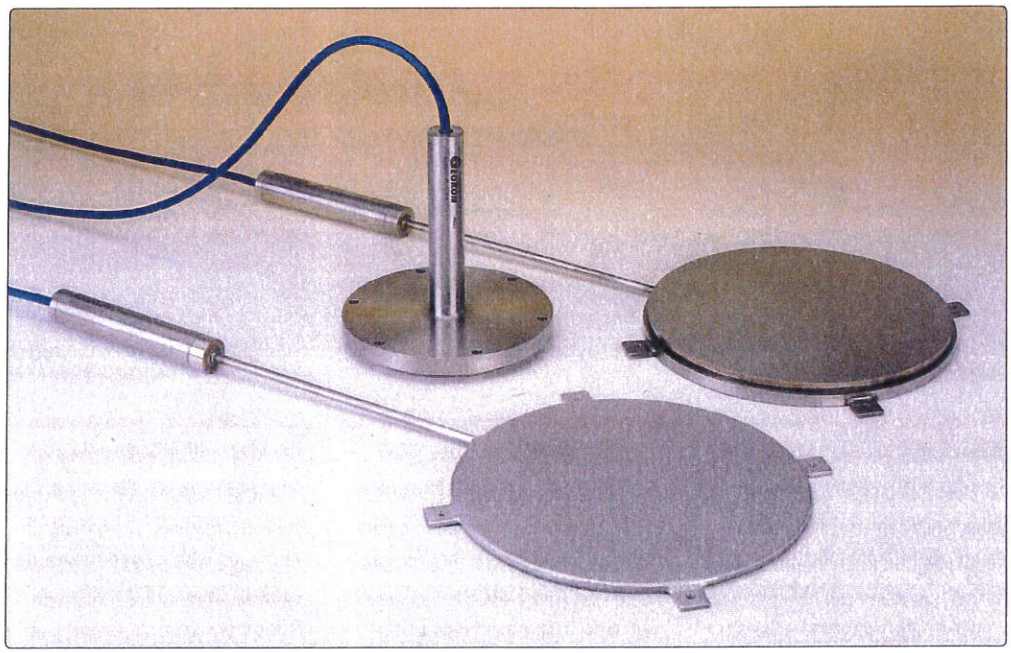
Earth Pressure Cells

Applications

Earth Pressure Cells provide a direct means of measuring total pressures, i.e. the combination of effective soil stress and pore water pressure, in or on...

- **Bridge abutments**
- **Diaphragm walls**
- **Fills and embankments**
- **Retaining walls surfaces**
- **Sheet piling**
- **Slurry walls**
- **Tunnel linings**

They may also be used to measure earth bearing pressures on foundation slabs and footings and at the tips of piles.



Model 4800 Earth Pressure Cell (front), Model 4820 Jackout Pressure Cell (center) and Model 4810 Contact Pressure Cell (rear).

Operating Principle

Earth Pressure Cells are constructed from two stainless steel plates welded together around their periphery and separated by a narrow gap filled with hydraulic fluid. External pressures squeeze the two plates together creating an equal pressure in the internal fluid. A length of stainless steel tubing connects the fluid filled cavity to a pressure transducer that converts the fluid pressure into an electrical signal transmitted by cable to the readout location.

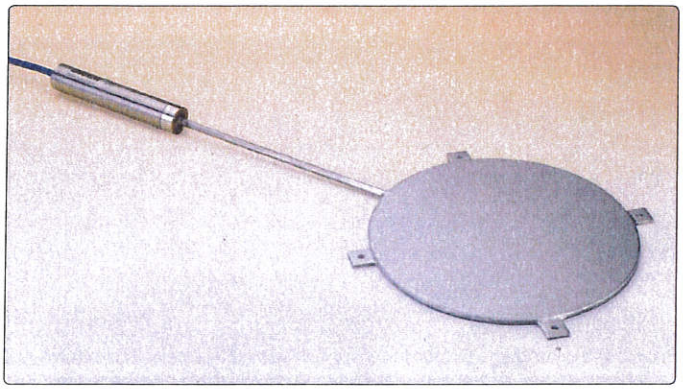
Advantages & Limitations

The 4800 Series Earth Pressure Cells use vibrating wire pressure transducers and thus have the advantages of long term stability, reliable performance with long cables and insensitivity to moisture intrusion. All models also include a thermistor for temperature measurements and a gas discharge tube for lightning protection. Where dynamic stress changes are to be measured a semiconductor type pressure transducer is substituted (see Model 3500).

Cell performance depends strongly on the surrounding soil properties. It would be prohibitively expensive to calibrate a cell in the soil type specific to the application being contemplated. However, studies have shown that the most consistent cell performance is achieved using cells of maximum stiffness with aspect ratios D/t >10 (D is the diameter of the cell, t the thickness). With Geokon cells, maximum stiffness is achieved by using hydraulic oil with less than 2 ppm of dissolved gas and aspect ratios generally greater than 20 to 30. Tests on Geokon cells in various types of soil have shown that the cells over-register the soil pressure by less than 5 percent. This is probably no greater than the inherent variability of the soil pressure distribution in the ground.

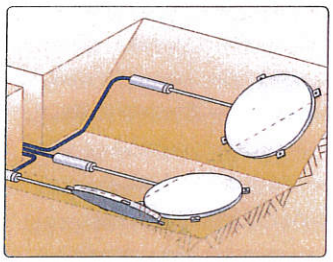
Typical of all closed hydraulic systems, earth pressure cells are sensitive to temperature changes which cause the internal fluid to expand at a different rate than the surrounding soil giving rise to spurious fluid pressure changes. The magnitude of the effect depends to a greater extent on the elasticity of the surrounding soil, i.e., on the degree of compaction and confinement, and is difficult to predict and correct for. The built-in thermistor is helpful in separating these spurious effects from real earth pressure changes.

Model 4800, 4815 Earth Pressure Cells



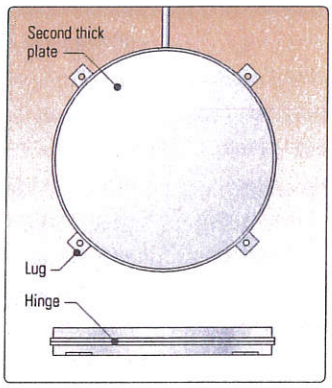
• *Model 4800 Earth Pressure Cell.*

Model 4800 cells are constructed from two thin pressure sensitive plates. They can be positioned in the fill at different orientations so that soil pressures can be measured in two or three directions. Special armored cables are recommended in earth dam applications.



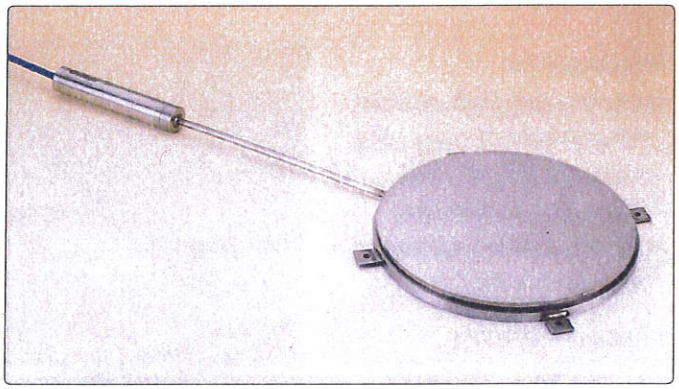
• *Model 4800 Earth Pressure Cells installed in fill for soil pressure measurement in three directions.*

The **Model 4815** is a special cell that effectively reduces the severity of point loading when used in granular materials. The modification uses two thick plates welded together at a flexible hinge that helps provide more uniform pressure distribution.



• *Model 4815 pressure cell, with two thick plates, for use in granular materials.*

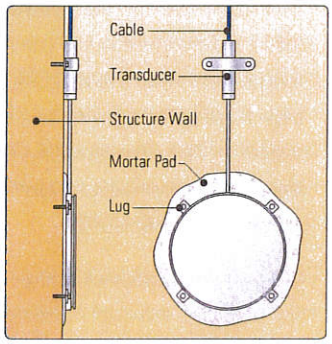
Model 4810 Contact Pressure Cells



• *Model 4810 Contact Pressure Cell for attachment to existing concrete surfaces.*

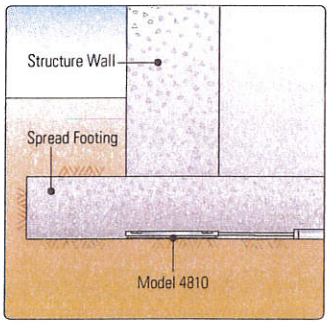
The Model 4810 Contact Pressure Cell is designed to measure soil pressures on structures. The backplate of the cell which bears against the external surface of the structure is thick enough to prevent the cell from warping. The other plate is thin and is welded to the backplate in a manner which creates a flexible hinge to provide maximum sensitivity to changing soil pressures.

Lugs on the side provide a means of mounting the cell to concrete forms or to steel or concrete surfaces. A mortar pad beneath the backplate ensures good contact with the structure surface. Cells are best installed flush with the surface to which they are attached. The fill material next to the cell should be screened to remove pieces larger than 10 mm.

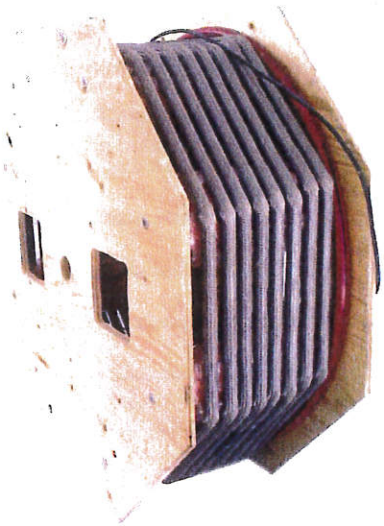


• *Side and frontal views of the Model 4810 installed on existing structure.*

Cells installed at the base of slabs and footings to measure bearing loads should always be positioned inside the concrete with the sensitive face pressed against the compacted fill. Cells placed in the fill below the concrete often become decoupled from the soil pressure due to the impossibility of adequately compacting the fill around the cell.



• *Model 4810 installation in a spread footing.*



Description

The ShapeAccelArray Field model (SAAF), is the most commonly used model of SAA. All SAA models have rigid segments separated by flexible joints. Triaxial MEMS gravity sensors measure tilt in each individual segment. SAAFs produce data equivalent to inclinometer data. Each SAA is a fully-calibrated measuring instrument with a length of up to 100 meters, delivered on a reel, and installable in very small diameter casing. As a result, installation is rapid and lower in cost, and much larger deformations can be monitored. An SAAF may be installed near vertical to track the magnitude and direction of lateral deformation, or near horizontal to track vertical deformation. It can be also be installed along the cross-section of tunnels and used in "mixed H/V" mode to measure convergence. Due to the MEMS sensors in the SAAF, it is possible to use the SAAF to monitor 3D vibration data at up to three selected locations along the instrument. Temperature data are collected every eight segments along the SAAF.

SAAF installations are designed for either manual or automated measurements with a PC or data logger and can be powered with either mains or solar power. Other custom solutions are also available, contact Measurand for more details. All communications in the array are digital and carried along a cable to the reading device. Standard software required to collect, process, and view SAAF data is available free of charge from the Measurand website within the SAASuite software package. A Measurand interface is required between an SAAF and logger or computer. Interface functions include protocol conversion, power control, and surge protection. Interfaces include SAA232, SAA Field Unit, and SAAUSB.

Related products: SAA232, SAA Field Unit, SAAUSB, SAAPZ

Specifications

Physical Properties:	
Segment length[1]:	305 mm or 500 mm (joint centre to joint centre)
Maximum length of SAAF:	100 m (500 mm segments) or 60.96 m (305 mm segments)
Maximum number of segments:	200
Length of unsensorized bottom loop:	60 mm

Length of unsensorized top portion:	130 mm
Length of hardened cable (inside PEX):	175 mm
Length of PEX tubing	1.5 m standard
Length of communication cable:	Standard 15 m, (13.5 m extending past the PEX tubing)
Weight:	0.6 kg/m
Joint diameter in extension:	25 mm
Joint diameter in compression:	27 mm
Maximum tensile resistance:	320 kgf
Maximum axial compression:	45 kgf (in casing), 22 kgf (no casing)
Minimum axial compression to provide snug fit in casing:	10 kgf
Maximum joint bend angles:	45° (larger angles permitted when stored on factory reel in factory orientation)
Smallest bend radius which allows for extraction:	3.5 m
Storage temperature:	-40°C to 60°C
Installation temperature[2]:	-5°C to 60°C
Operating temperature:	-20°C to 60°C
Waterproof to:	980 kPa
Power requirements:	12 VDC at 2.5 mA/segment

Dynamic Acceleration Measurements:

Range:	± 1.7 G
3dB Bandwidth:	50 Hz
Noise floor of MEMS:	110 $\mu G/Hz^{0.5}$
Data rate:	SAA232: 38.4 kbps to 230.4 kbps

Static Shape Measurements:

Angular range of MEMS sensors:	± 360° (software selection required for 2D/3D modes)
Range of 3D mode (vertical):	± 60° with respect to vertical (SAARecorder alert at ±70° w.r.t. vertical)
Range of 2D mode (horizontal):	± 60° with respect to horizontal
Range of 2D mode (mixed H/V):	± 180° with respect to horizontal
Long-term accuracy relative to starting shape[3,5,6]:	± 1.5 mm for 32 m SAA

Short-term resolution relative to starting shape[4,5,6]:	± 0.5 mm for 32 m SAA
Long-term accuracy of tilt/segment within 20° of vertical[3, 5, 6]:	± 0.0005 rad = 0.029°
Azimuth error in joints:	< ±0.25°
Orthogonality within segments:	± 0.1°

[1] Custom segment lengths between 200 mm and 305 mm are available at extra cost, contact Measurand for more information.
[2] Note that most PVC cement for the 27 mm ID PVC conduit is limited to working temperature of 0°C, though special low temperature PVC cement which will work to -20°C is available. Also, flexible SAA joints may be damaged by abrupt bending at low temperatures. As such installation below -5°C ambient must be accompanied by a means of warming the SAA joints and any cemented PVC couplings.
[3] Value based on field measurements of vertical arrays for 1.5 years of operation.
[4] Short-term ≤ 24 h.
[5] Value based on averaging 200 – 1000 frames per reading.
[6] Specification is for 3D mode within ± 20° of vertical. Vertical accuracy degrades with angular deviation from the vertical.

Instruction Manual

SAA Install Kit

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1. Introduction

The SAA Install Kit includes various parts which make preparing for SAA installation more convenient, and which produce a secure installation in less time. The PVC fittings in the kit surround the PEX at the cable end of the SAA. A blunt-nose setscrew threaded into the fittings holds a vertical SAA at its set azimuth while maintaining axial compression to snug the joints, and provides a secure hold at the cable end of horizontal SAAs. The fittings help keep surface water out of the 27 mm ID PVC conduit holding the SAA, and help prevent outside forces and moments from being applied to the SAA. The kit eliminates slotting, taping, and clamping to hold the SAA.

2. Description

The SAA Install Kit includes various parts which make preparing for SAA installation easier and more convenient. Several of the parts included, such as the end cap and PVC cement and primer, are needed in the installation process described in the SAA Installation Guide (available on the Measurand website at the following address: http://measurandgeotechnical.com/Installation_Guide_2011.pdf). These parts may sometimes be difficult to find locally, so they have been included for convenience.

Two versions of kit are available: with tools for first-time users, and without tools for repeat users. The kit is for vertical or horizontal installations. The content of each kit is outlined in Table 2.1 and Table 2.2 below. Each kit contains one pre-assembled top fittings stack, shown in Figure 2.1a. This stack incorporates two threaded fittings so that the SAA can be retrieved at any time and replaced without cutting the casing. Due to the height of the stack, it is most suitable for use when stick-up above ground is not an issue. Extra fittings are also included in case the pre-assembled stack needs to be modified. For example, the short stack shown in Figure 2.1b is suitable for burial underground but the conduit will need to be cut in order to retrieve the SAA. Note that both the fittings stacks shown in Figure 2.1 include a set screw. The set screw section is used to keep compression on the top of the SAA. It replaces the saw cuts and gear clamps described in the SAA Installation Manual. A tapping tool is also included for cases where the pre-tapped fittings will not suffice.

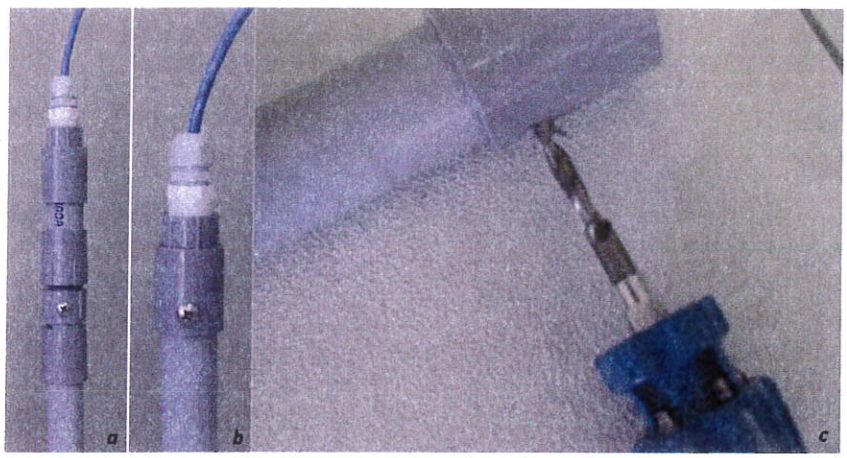

Figure 2.1 – Possible assemblies for fittings in SAA Install Kit. (a) Pre-assembled fittings stack provided in kit, suitable for cases where the SAA conduit can have some stick up. (b) Short stack of fittings, suitable when the SAA conduit must be buried underground. (c) Tapping hole for the set screw through the coupling and PVC conduit.

Table 2.1 - SAA Install Kit #1 (with tools)

Quantity	Item Description
1	Pre-assembled top fittings stack
1	3/4" NPT Liquid-Tight Male Straight Connector
20'	3/4" Liquid-Tight nonmetallic Conduit
1	Reducing Bushing, NPT ¾" reduced to ½"
1	Schedule 40 PVC Male Terminal Adapter 1"
1	Schedule 40 PVC Female Adapter 1"
2	Schedule 40 PVC Coupling 1"
1	Gland ½" NPT
1	18-8 SS Sealing Pan Head ¼"-20
1	1" PVC End Cap
6	large Tie Wraps
1	PVC Quick – Set Cement with MSDS
1	PVC Primer with MSDS
1	Teflon Tape
1	3/4" PEX Tubing Cutter
1	Drill / Tap Bit ¼"-20 NC
1	Multi – Screwdriver

Table 2.2 - SAA Install Kit #2 (without tools)

Quantity	Item Description
1	Pre-assembled top fittings stack
1	3/4" NPT Liquid-Tight Male Straight Connector
20'	3/4" Liquid-Tight nonmetallic Conduit
1	Reducing Bushing, NPT ¾" reduced to ½"
1	Schedule 40 PVC Male Terminal Adapter 1"
1	Schedule 40 PVC Female Adapter 1"
2	Schedule 40 PVC Coupling 1"
1	Gland ½" NPT
1	18-8 SS Sealing Pan Head ¼"-20
1	1" PVC End Cap
6	large Tie Wraps

3. Sealing the top of the PVC conduit using the SAA Install Kit

Use of the pre-assembled fittings stack is shown in Figure 3.1. The fittings can be used for vertical and horizontal installations, as well as the SAA+PVC installations described in the SAA Installation Guide. In order to use the pre-assembled fittings stack, you should first separate the stack into two parts by unscrewing the threaded joint located directly above the set screw.

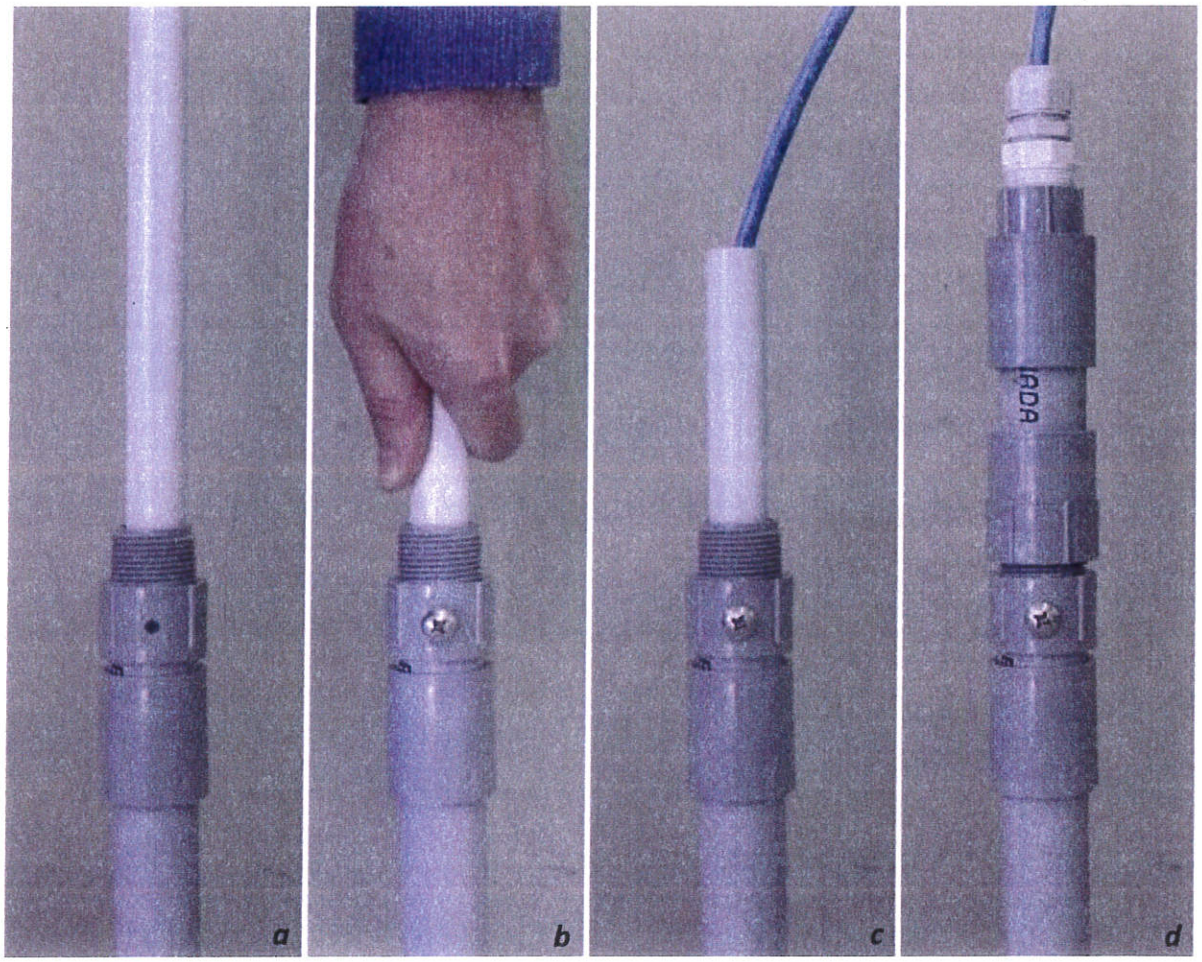

Figure 3.1 – Using the pre-assembled fittings stack during SAA installation. (a) Glue bottom portion of the pre-assembled fittings stack to the PVC conduit. (b) Apply compression to the top of the SAA and tighten set screw, see SAA Installation Guide for more information on compressing the SAA. (c) Remove excess PEX using the PEX cutter. (d) Thread the top portion of the pre-assembled stack over the cable and screw into the bottom portion. Tighten the gland at the top until the rubber seals the cable.

If you are doing an SAA+PVC installation, you should do step 1 as shown in Figure 3.1a then tighten the set screw so that the SAA will be secure during insertion of the SAA+PVC into the borehole. At that point, the set screw can be loosened and you can resume with step 2 as shown in Figure 3.1b. For horizontal installations, you will not need to compress the array but you will still need to tighten the set screw to secure the SAA.

Once the top of the PVC conduit has been sealed as shown in Figure 3.1, the next concern is protecting the cable until it reaches the data logger. It is recommended that the cable be placed inside a conduit to protect it from mechanical damage. The SAA Install Kit includes 7.6 m or 20' of ¾" flexible conduit to protect the cable. The ¾" conduit can be inserted directly into the Enclosure box through small knock outs located on the bottom of the box. A 3/4" NPT Liquid-Tight Male Straight Connector included in the kit will seal the conduit at the enclosure so that insects and other small pests cannot gain access to the enclosure.

Since the PVC conduit containing the SAA has been sealed, it is not necessary for the flexible conduit to cover the entire cable. If the top of the SAA is protected using a well head covering or some other buried structure, it is possible to use zip ties provided in the kit to hold the conduit in place under the protective casing (Figure 3.2a). It is also possible to do cable splices or attach items such as the SAASPD surge protection device at this point (Figure 3.2b).

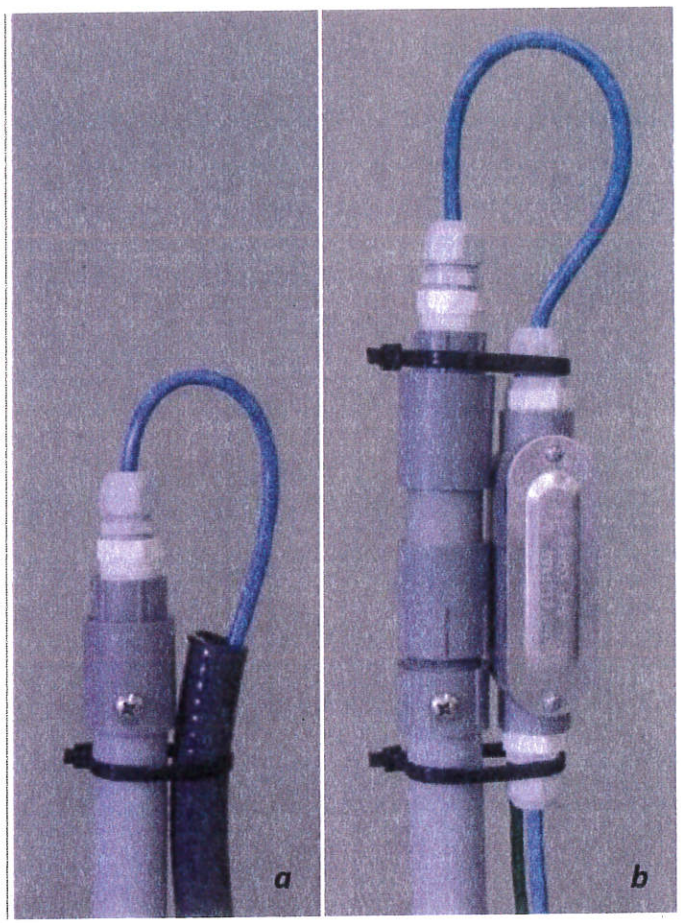

Figure 3.2 – Finishing off SAA installation under a protective well head. (a) Attaching flexible conduit to PVC conduit using zip ties. (b) Attaching SAASPD at top of borehole.

Manual

ShapeAccelArray

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Important details about proper handling of SAAs are presented in Appendix A. **SAAs which are not handled as discussed in the guidelines contained herein and in Appendix A, will not be covered under warranty.**

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1. Introduction

Measurand's ShapeAccelArray (SAA) is a flexible, calibrated 3D measuring system. It measures 2D and 3D shape and 3D vibration using a compact array of MEMs accelerometers and proven ShapeTape / ShapeRope algorithms. Unlike collections of tilt sensors or arrays of sensors that bend in a single direction, SAAs require no other guides or fixturing. They bend freely, without a preferred axis, in 2 degrees of freedom and may be mounted vertically or horizontally. SAAs also roll up for shipping and storage.

SAAs do not significantly extend or compress, and therefore should be oriented perpendicular to the anticipated displacement direction: vertical, horizontal, or in between. Measurements taken with SAAs are taken relative to stable ground, or to a survey point.

Gravity measurements by triaxial MEMS accelerometers allow 3D shape to be determined when segments are within 60° of vertical. Otherwise, software must be set to calculate only 2D shape. SAAs can also capture 3D real-time vibrations, such as from earthquakes or pumping of grout.

SAAs have been used in many different applications such as:

- In-situ monitoring of unstable slopes (SAAF)
- Monitoring of civil engineering structures (SAAF)
- Monitoring of mines and excavations (SAAF, SAAScan)
- Measuring drill-hole shape (SAAScan)
- Laboratory research (SAAF, SAAFlex, SAAR)

SAAs can be read using data loggers or using computers running specialized Measurand software.

This manual covers the background theory of how SAAs work, as well as how to install and use SAAs. Discussion herein covers the use of the SAA field model (SAAF), which is the most commonly used model of SAA. In most cases, the discussion herein applies for the other models of SAA, but there are some differences which must be considered. These differences between SAAF, SAAScan, SAAFlex, and SAAR are discussed in their respective manuals.

2. Background Theory

This chapter is broken down into two major sections:

1) Terminology and what to specify when ordering.
2) How SAA works, and how to maximize repeatability

2.1 *Anatomy of an SAA*

An SAA is an array of sensorized rigid segments separated by flexible joints. Each segment contains 3 MEMS accelerometers which measure tilt along X, Y and Z axes. The accelerometers also provide triaxial measurement of vibration at selected segments. As shown in Figure 2.1, an SAA has the following major components: segments and joints, communication cable, PEX tubing, eyelet, X-marks, on-reel markings, and a label. These are described in more detail below.

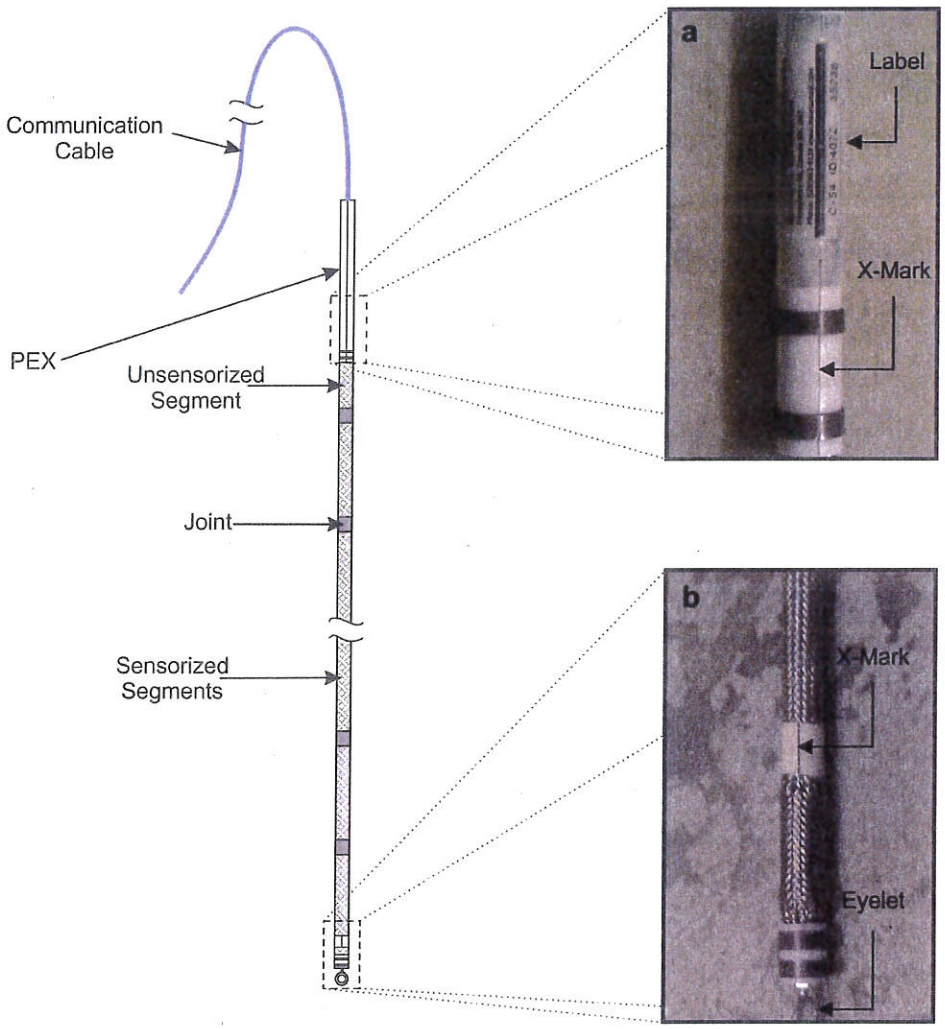


Figure 2.1: Anatomy of an SAA. (a) Placement of X-mark and SAA label on the PEX tubing at the near end of the SAA. (b) Placement of the X-mark and eyelet at the far end of the SAA.

2.1.1 Segments and Joints

SAAs segments are separated by flexible joints. Figure 2.2a shows internal joint seals. An SAA has two layers of stainless steel braid. Both braids provide twist resistance and pull strength. The outer braid also provides primary protection against abrasion. SAA also has an overall waterproof covering which is for the most part hidden by the outer braid. Care must be taken to prevent the protective coverings of the SAA from being punctured or abraded. For more information regarding SAA handling, see Section 4.2.

2.1.1.1 Joints

The layers of braid and the internal joint construction are designed to minimize twisting of the joints. The joints on a SAA are designed to expand under axial compression and contract in extension. Note that joints are non-circular due to the reeling and unreeling process. SAA are meant to be installed inside a 27 mm +/- 1 mm conduit. When pulling the SAAF into the conduit, the typical joint width is 22 mm to 24 mm wide. Once the joints have been snugged into the conduit, the typical joint width is 27 mm +/- 1 mm. This is shown in Figure 2.2b, where the joint is expanded to touch the inside of the clear conduit. For horizontal installations, larger diameter conduit can be used. The SAA will remain at the bottom of the horizontal conduit so long as a low-friction conduit such as PVC or HDPE is used.

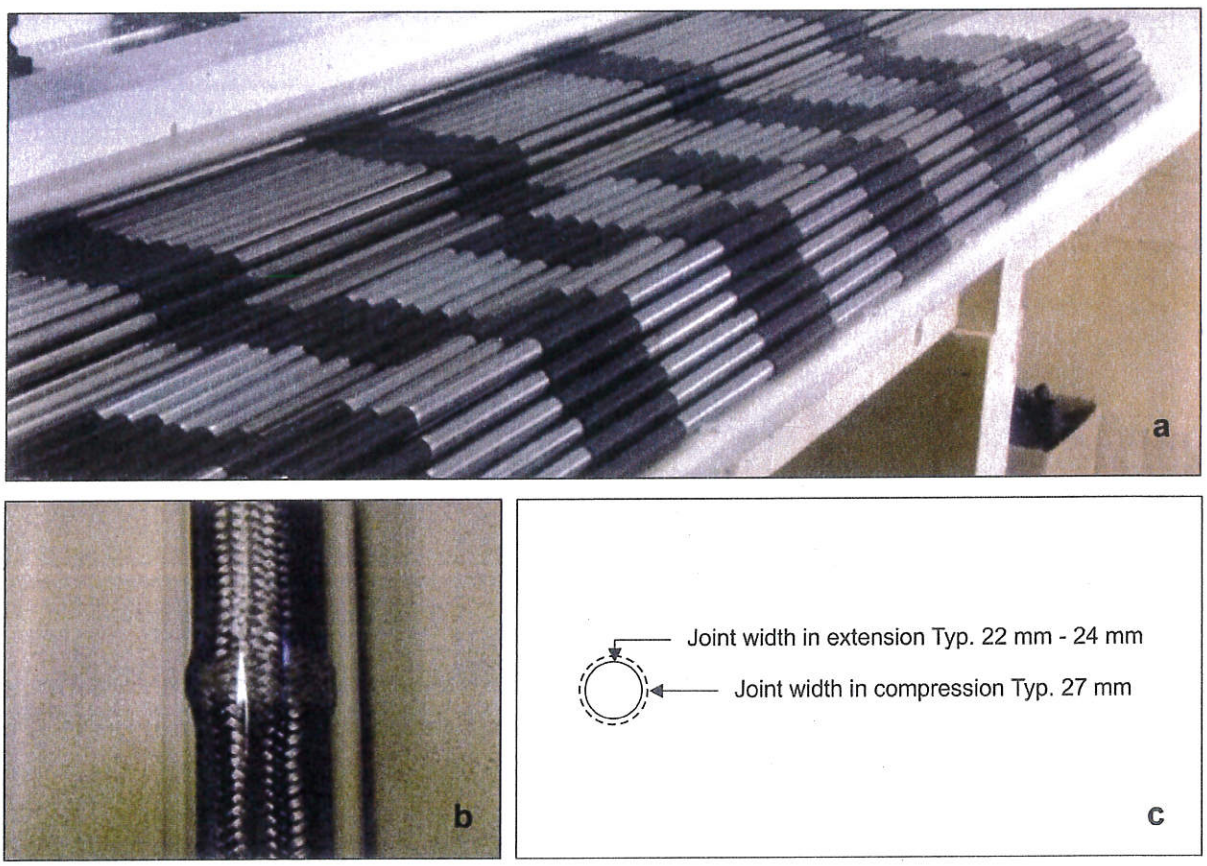


Figure 2.2: Segments and joints. (a) SAA segments joined into octets. (b) Joint in compression inside clear conduit. (c) Typical joint dimensions.

2.1.1.2 Sensorized Segments and Octets

With the exception of one mechanical-only segment at the cable end of the SAA, segments contain accelerometers. Segments are measured joint center to joint center. In standard SAAs, the segment

length is either 305 mm (1') or 500 mm (1.64'). Each sensorized segment contains MEMS accelerometers. Sensorized segments are organized in groups of eight called octets, as shown in Figure 2.2a. Each octet has one segment which also contains a microprocessor and digital temperature sensor. SAAs that have a number of segments not divisible by eight have one partial "octet" with fewer than eight segments, always located at the far (non-cable) end of the SAA.

2.1.1.3 Magnetometers

Any SAA can be ordered with magnetometers installed in selected segments. Magnetometers are electronic compasses that provide accurate X-mark heading (azimuth) data relative to magnetic north. Magnetometers should not be used if the site is not magnetically "clean" (i.e. free of ferrous material or magnetic sources such as strong electrical currents). Magnetometers do not increase the diameter or increase the number of segments in the SAA. The magnetometers are placed in the same segments as MEMS accelerometers. Typically magnetometers are installed near the top, middle, and bottom of the SAA. This is done to provide overall azimuth and relative azimuth along the SAA. Data from the magnetometers are used by Measurand software to reference the SAA data to magnetic north. The data are also used to verify and if necessary correct any twist that might have inadvertently been introduced. This is useful when SAAs are very long (>30 m). Magnetometers are also useful on short SAAs suspended at depth, such as at the end of a long length of PEX.

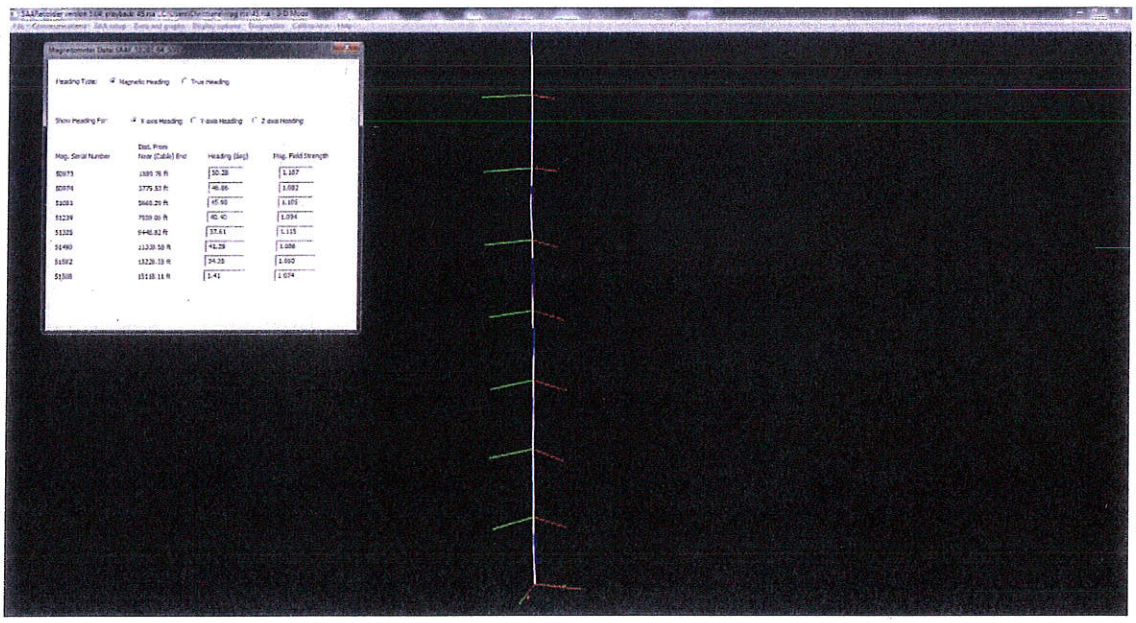


Figure 2.3: View of SAA with magnetometers in SAARecorder. Magnetometer data is shown with azimuth and magnetic field strength information.

2.1.1.4 Unsensorized segment

Every SAA contains one unsensorized segment at the cable end of the SAA (see Figure 2.1). This unsensorized segment is used to join the cable to the SAA. The length of the unsensorized portion of the SAA is 130 mm measured from joint center to the PEX.

2.1.1.5 Eyelet

In addition to the unsensorized segment at the top of the SAA, there is a short piece of PEX tubing at the bottom of the SAA to which an eyelet is connected (Figure 2.1b). The eyelet is used to pull the SAA into

PVC conduit as discussed in Section 4.4.1. The overall length of this attachment is 50 mm, measured from the far end of the last segment to the far end of the eyelet.

2.1.1.6 Overall SAA length

It is important to note that the SAA has both sensorized and unsensorized portions. The overall length of the SAA is therefore not the same as the sensorized length. This is important when deciding what length SAA to purchase. The overall length of the SAA can be determined as shown below:

$$L = xL_s + L_u + L_e$$

Where:

L = Overall length

x = Number of segments

L_s = Segment length

L_u = Unsensorized length at top of SAA = 130 mm

L_e = Eyelet at bottom of SAA = 50 mm

Note: If you are going to install the SAA so that it is entirely underground, you will need to take into account the length of the PEX as well when determining the overall length of the SAA. The shortest PEX length possible is 150 mm. This is the length of hardened cable inside the PEX tubing. This 150 mm section of cable, which cannot be bent, is measured along the PEX starting at the intersection between the top unsensorized segment and the PEX.

2.1.2 Cable

The cable attached to the SAA is used to provide power to the instrument and to allow for communications between the SAA and a data logger or computer. Cable length can be quite long due to the digital communication protocol used by SAA. The maximum cable length for a given SAA is determined by the number of segments, the number of magnetometers, if any, and any additional equipment sharing the cable, such as SAAPZ piezometers. Maximum cable length tables for SAAs with no magnetometers or piezometers are presented in Appendix B.

2.1.3 PEX

PEX tubing is used in SAA construction to protect the communication cable from damage, to provide a secure way of retrieving the SAA, and to set the azimuth of the SAA if the SAA itself is not visible from the surface. Each SAA comes with 1.5 m (5′) of ¾″ PEX attached at the top. If this length is not sufficient to reach the surface or end of a borehole, it is possible to extend the PEX using extra PEX and a Measurand PEX Extension Kit. Clients can either source additional ¾″ PEX locally, or buy it directly from Measurand. The PEX couplers provided in the kit are designed to provide a solid mechanical connection to hold the weight of the SAA, and to resist any twist at the PEX connection; something that traditional PEX couplers cannot do.

In cases where the PEX tubing is extended beyond 10 m (32′) in length, the PEX will provide only approximate azimuth control. For best results in these cases, it is recommended that magnetometers be

integrated into the SAA, or that the SAA+PVC installation method (see Section 4.4.1) be used, with azimuth control provided by PVC extending to the surface.

2.1.4 X-Marks

X-Marks are placed at the top and bottom of the SAA as shown in Figure 2.1. The software calibrated X axis for each sensor is aligned with the X-Marks. Installers often align the X-Mark at the top of a vertical SAA so that it lines up with the expected direction of movement (e.g. downslope for landslide monitoring). The top and bottom X-Marks are also used to verify that the SAA has not been twisted by mishandling. See Chapter 8.7 for more details.

2.1.5 On-reel Dots

When an SAA is reeled or unreeled without applying any torsional strain, there is a slight change in heading at each joint due to the helical shape of the winding. The same thing occurs in any cable, hose or rope which is reeled or unreeled. The twist incurred during the reeling process is elastic and will be recovered during the unreeling process. When the SAA is unreeled into a conduit, the outward facing "On-reel state" marks will rotate and no longer be facing at the same azimuth. This is expected and does not indicate that mechanical twist has occurred at the joints. In fact, the joints are resuming their factory-calibrated headings. It should not be confused with mechanical twist, which can remain in the joints as an error, after unreeling. Mechanical twist is a plastic yielding response arising from the application of additional torsional moment, and is to be avoided.

On-reel state of the SAA is marked at the factory. If your SAA does not have the on-reel dots as shown in Figure 2.4a, then you should put them on yourself using the procedure shown in Appendix B.

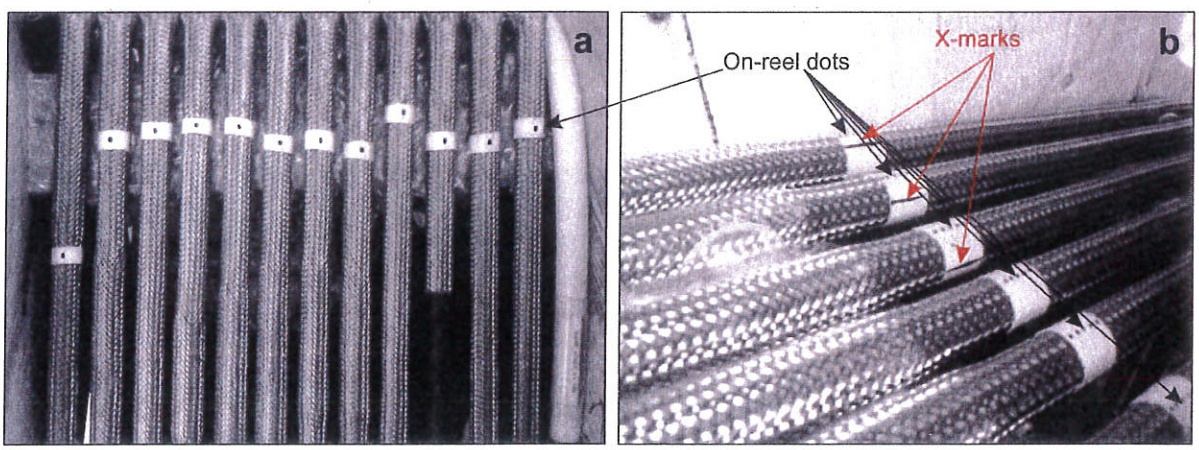


Figure 2.4: On-reel dots on SAA. (a) On-reel dots placed at factory. (b) Orientation of X-marks versus on-reel dots.

2.1.6 Reel

SAAs are shipped on a wooden reel designed to help make installation and storage of the SAA easier. A typical SAA on its reel is shown in Figure 2.5. The SAA should only be off the reel when it is being used to measure shape. When not in use, it should be placed on its reel for storage, with the joints bent the same way as at the factory. Other treatment can affect the mechanical integrity of the joints.

Figure 2.5: SAA placed on a reel for storage.

2.1.7 Reel Label

Each reel is labeled using a standard label as shown in Figure 2.6. The label contains the specifications for the SAA from the customer Purchase Order. Information included are: QA date, SAA serial number, SAA type, segment length, sensorized SAA length, unsensorized SAA length, total SAA length, cable length, whether or not there is an amphenol connector on the SAA, the number of segments with magnetometers, and any special notes. In the example below, a customer has requested a 60 m SAA constructed with 500 mm segments. The customer has also requested that extra X-marks be placed every 2 m.

measurand
SHAPE ADVANTAGE

2111 Hanwell Rd
Fredericton, NB,
Canada
E3C 1M7

SAA Specifications

QA Date:	14-Nov-2012	Total SAA Length:	60.23 m
Serial Number:	51999	Cable Length:	15 m
SAA Type:	SAAF	Amphenol Connector:	No
SAA Segment Length:	500 mm	Number of Magnetometers:	0
Sensorized SAA Length:	60 m	Special Notes:	
Unsensorized SAA Length:		Additional X-Marks every 2Meters	
Top ("cable end"):	180 mm		
Far end:	50 mm		

www.MeasurandGeotechnical.com • P: [illegible] • F: [illegible] • Email: [illegible]

Figure 2.6: Example of reel label with SAA specifications as per purchase order.

2.2 How SAAs Work

2.2.1 Position Determination

The SAA uses MEMS accelerometers to determine the tilt of individual segments with respect to gravity, as shown in Figure 2.7. MEMS accelerometer axes are aligned in software, according to calibration files created during manufacture, to form a consistent orthogonal set for each of X, Y, and Z.

For vertical SAAs, chain-wise 3D calculations are made in software to determine the 3D position and orientation of each segment of the SAA. Horizontal SAAs cannot sense movement within the horizontal plane, so calculations are 2D. In either case, data are obtained over a large angular range not possible with conventional inclinometers. The calculations are relative to a starting point, usually taken to be stable ground. The data set for SAA is represented as a polyline in two or three dimensional space, with vertices representing the position of the joint centers.

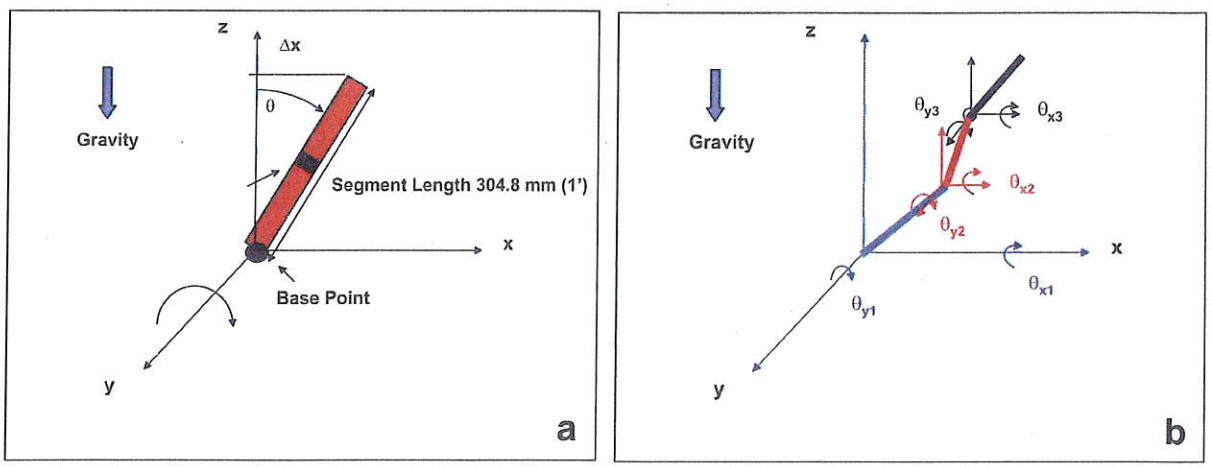


Figure 2.7: (a) Tilt for single segment. (b) Tilts and positions for multiple segments

2.2.2 Accuracy of SAA

MEMS accelerometers used in SAAs measure tilt over a 360 degree range. Accelerometers like these have sinusoidal response curve, so they are not equally sensitive at all angles. However when these accelerometers are mounted properly and used in combination with suitable automated math, they can accurately sense tilt throughout all angles of a sphere. When horizontal or near-horizontal, SAA provides data within a vertical plane. When vertical, SAA provides true 3D data for the polyline shown in Figure 2.7. The SAA does not extend or compress.

Statements of accuracy should specify whether it applies to the absolute ***shape*** (i.e. the polyline specified above), or to ***deformation*** of the shape (i.e. the change in the polyline to ***another*** polyline). Sometimes "accuracy" is used to mean "accuracy of absolute shape", and "precision" (sometimes referred to as "repeatability") is used to mean "accuracy of deformation". Precision is a measure of the repeatability of a measurement and should include a long time scale. For example, in the case of an inclinometer or SAA precision can be thought of as follows: "How well do my measurements repeat if taken for the same stable object day after day, or year after year?" It is also of interest to know how small a change can be detected when measuring a change (such as the tilt of a borehole). This is referred to as the "resolution" of the instrument. Normally it implies a short measurement timescale, e.g. 24 hours versus a year, a year being more relevant to "precision".

Based on this definition of precision given above, it can be seen that precision can properly be applied to either the shape or the deformation, so we prefer speaking of "accuracy of absolute shape" and "accuracy of deformation".

In almost all geotechnical applications, it is important to track the deformation. In most cases knowledge of an absolute shape is only needed to understand the borehole or installation variables which can affect deformation monitoring. In these cases the "accuracy of deformation" is more important.

The typical accuracy of deformation value given for a 32 m long SAA is 1.5 mm. Although the accuracy degrades for longer SAAs, it does so in relation with the square root of the length of the SAA rather than degrading linearly. For example, a 64 m SAA will have an accuracy of deformation of 2.1 mm, rather than 3.0 mm.

Accuracy of deformation can be improved by averaging multiple samples together into a single reading. The accuracy improves in relation to the square root of the number of samples averaged together to produce a single reading. The number of SAA samples used to compute an average reading can range from 100 to 25500. The larger the number of samples the better the accuracy, but computational time also increases. It is recommended for most applications that the averaging interval be set to 1000.

SAAs manufactured since March 2010 have "Averaging in Array" capabilities. With AIA technology, the SAA is prompted to take a set number of samples and calculate the average. This results in a much more precise reading. Prior to the emergence of AIA, data were collected from the SAAs and the averaging was done either in the logger or the computer. Before AIA, data loggers could take over 30 minutes to collect readings. AIA allows data samples to be collected much faster than previously available. For example, taking the average of 1000 readings (standard averaging level) will take less than 10 s to output a value from the SAA.

3. Checking SAA Performance Prior to Installation

Prior to installing the SAA, it is desirable to check the performance of the SAA to verify that no damage occurred during shipping. This is done by completing diagnostics check using the SAARecorder application. The SAARecorder application is a free software utility accessible through the SAASuite software package. The SAASuite is free and available for download from the Measurand website at the following address: http://www.MeasurandGeotechnical.com/Software.html.

3.1 *Connecting the SAA to a Computer*

The most frequently used connection solutions for connecting an SAA to SAARecorder are as follows: connecting through an SAA232 or SAA232-5 interface unit, connecting through an SAA Field Power Unit (SAAFPU), or connecting through an SAAUSB adapter. For clarity, the discussion below only deals with connecting using an SAAFPU which is connected to the computer via a USB cable. Instructions for connecting wirelessly through the SAAFPU or via other interfaces are given in the appendices (Appendices D through G).

For safe operation of the SAA and SAAFPU, it is recommended that the following connection and disconnection sequences be followed:

3) To Connect:

a. Connect the SAA to the SAAFPU (See Section 3.1.1);

b. Connect the SAAFPU to the computer via the USB (See Section 3.1.2);

c. Open SAARecorder; then

d. Search for SAAs in SAARecorder.

4) To Disconnect:

a. Turn off SAARecorder to power down the SAA;

b. Disconnect the SAAFPU USB cable from the computer;

c. Disconnect the SAA from the SAAFPU

Note that the sequences are reversed. For ease of use, connection instructions are printed on the SAAFPU panel.

3.1.1 Connecting an SAA to the SAA Field Power Unit

Two separate methods have been provided for connecting SAAs to the SAAFPU. The method selected will depend on whether or not a circular connector is attached to the SAA (determined at the time of SAA purchase).

3.1.1.1 Connecting an SAA via 4-pin circular connector

For SAAs with a circular connector, connect the SAA directly via the 4-pin circular connector shown in Figure 3.1(A). In order to ensure a good connection, turn the connector until it is finger tight, and make

sure that the gap between the connectors does not exceed 1 mm (0.04"). This may require turning, then pushing, then turning again.

3.1.1.2 Connecting an SAA via 5-pin terminal block

SAAs without a circular connector connect to the SAAFPU via the 5-pin terminal block shown in Figure 3.1(B). An SAA cable contains five different wires which are used for power (red and black), communications (white and blue) and shielding (bare wire). These are connected to the terminal block in the order shown on the face plate of the SAAFPU. To open and close the terminal blocks, use a small flathead screwdriver. Prior to connecting the SAAFPU to the computer, make sure that each wire is securely fastened into the block.

3.1.2 Connecting the Computer to the SAA Field Power Unit

There are two different methods which can be used to connect a computer running SAARecorder to the SAAFPU. Communication between the SAAFPU can be done either via a wireless pair included with the SAAFPU, or via direct connection via a USB port on the computer (Figure 3.2). More details on the direct USB connection is given below. For more information on the wireless connection, refer to Appendix D. Once the computer is connected to the SAAFPU, SAARecorder will automatically power the SAA upon start-up. Note that the LED located above the 5-pin terminal block connector will light when SAARecorder is attempting to connect to or is connected to the SAA. For more information on how to use SAARecorder, please refer to the SAARecorder Manual found in SAASuite.

In order to connect a computer running SAARecorder to the SAAFPU directly via the USB port, connect the serial to USB cable provided with the SAAFPU to the serial port cable on the front facing plate of the SAAFPU. Once this is done, plug the USB connector into a USB port on the computer. The serial connection does not have any screws because it is meant to act as a quick release point in case the cable is snagged or the SAAFPU falls.

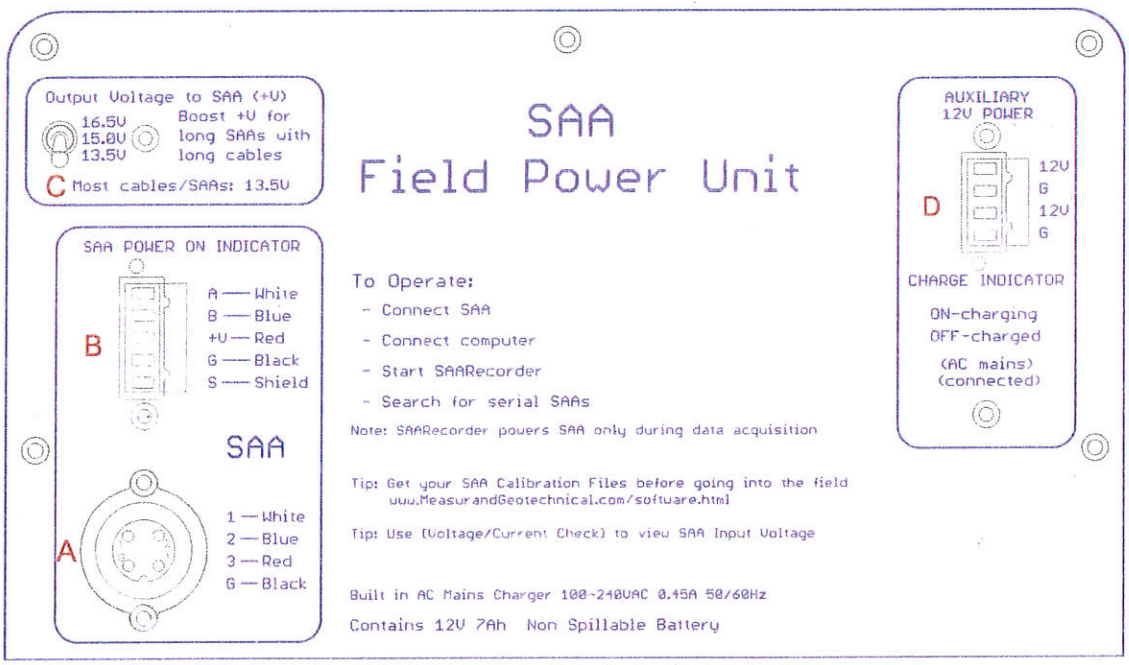


Figure 3.1. SAAFPU Interface. (A) 4-pin circular connector, (B) 5-pin terminal block, (C) Voltage selector, (D) Auxiliary 4-pin terminal block.

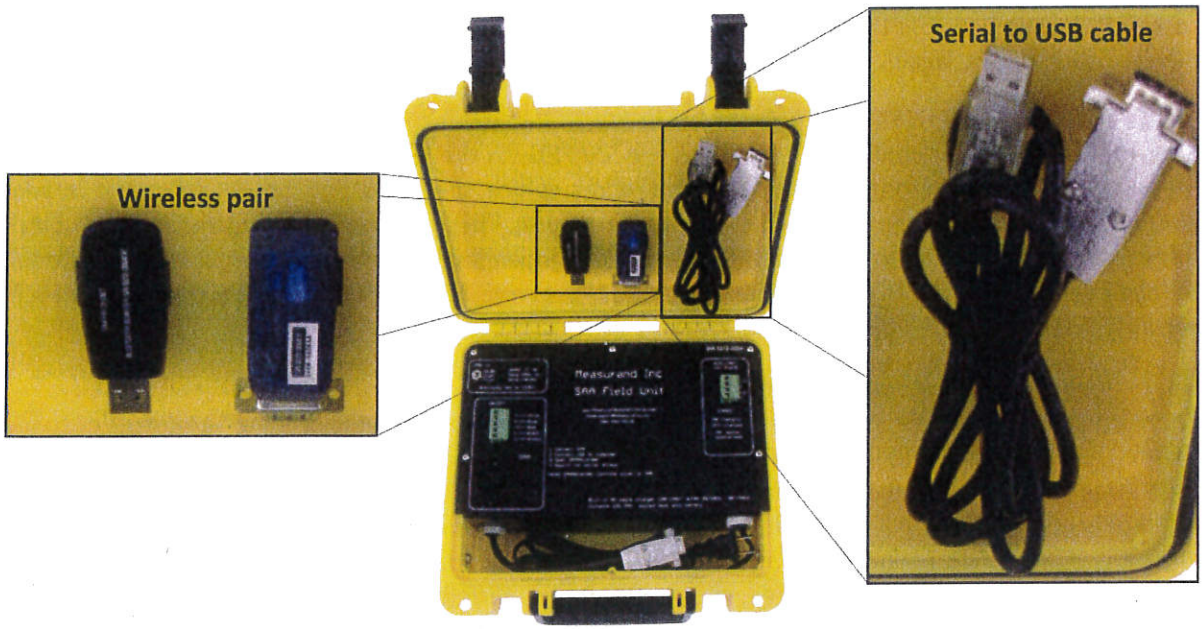


Figure 3.2: Options used for connecting the SAAFPU to a computer running SAARecorder.

3.2 *Using SAARecorder to Complete Diagnostic Tests*

The SAARecorder application is accessible through SAASuite. It can be started by clicking on the "SAARecorder" button in the main screen of SAASuite. Once SAARecorder is started, it may ask for confirmation of using 2-D or 3-D mode, and will then display the startup screen as shown in Figure 3.3.

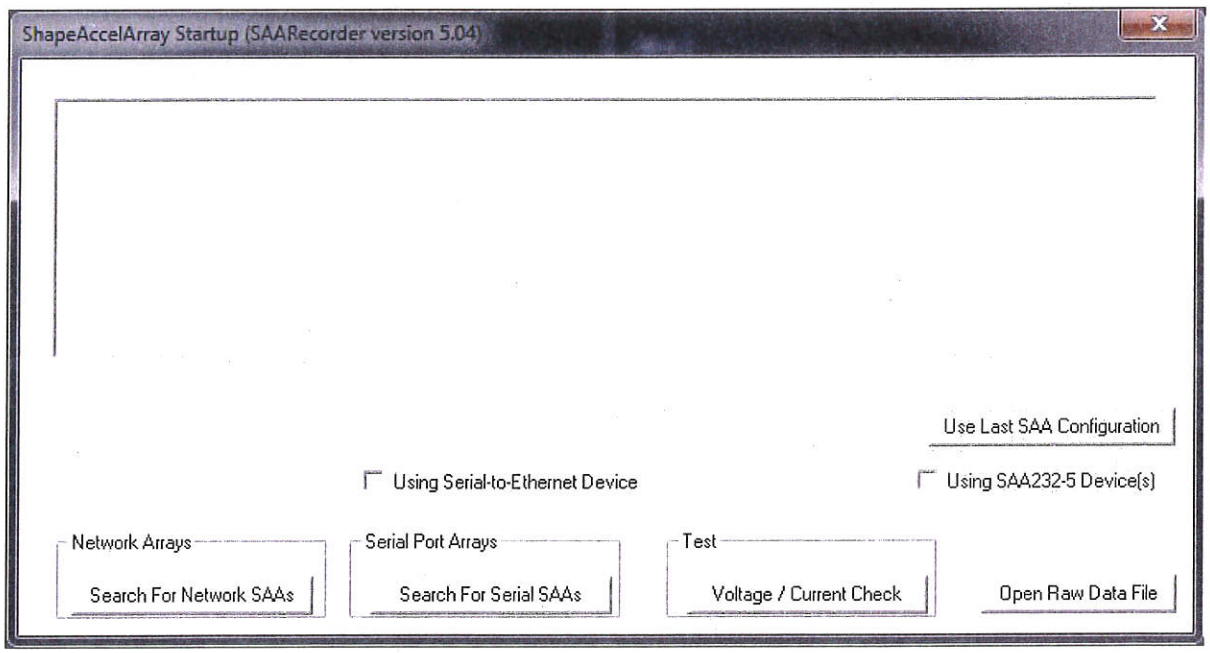


Figure 3.3. SAARecorder SAA startup screen.

In order to do complete diagnostic checks, you will need to go into the main window of SAARecorder. This is done by following the instructions below.

Prior to searching for SAAs, make sure that the "Using Serial-to-Ethernet Device" option is checked if you are using a serial to Ethernet (or Wireless Ethernet) converter, such as Lantronix WiBox or the RF416 wireless serial modem. If you are using one or more SAA232-5 devices, make sure that the "Using SAA232_5 Device(s)" option is checked. More details on using these interface devices are provided in Appendices D through G. Once this is done, press the 'Search For Serial SAAs' button.

After pressing the 'Search For Serial SAAs' button, it may be necessary to wait for up to about one minute for the PC to detect which SAAs are connected. You will be prompted to enter serial numbers for each of the SAA that are being used (see Figure 3.4 below). SAAs equipped with an SAATop (SAAs constructed starting in late 2011 generally have an SAATop) will automatically be added to the "SAA Numbers" field. For SAAs without an SAATop, it will be necessary to enter the serial numbers manually. Click 'OK' and SAARecorder will start searching for the SAAs listed.

Once in the main widow in SAARecorder, click on Diagnostics | Diagnostic Tests in SAARecorder to access the diagnostic test window (Figure 3.5). At this point it is possible to check the voltage for the SAA by clicking the "Voltage / Current Check". This will return values for voltage, current level, and temperature at the top of the SAA, as shown in Figure 3.6. Note that this check is only available for SAAs equipped with an SAATop.

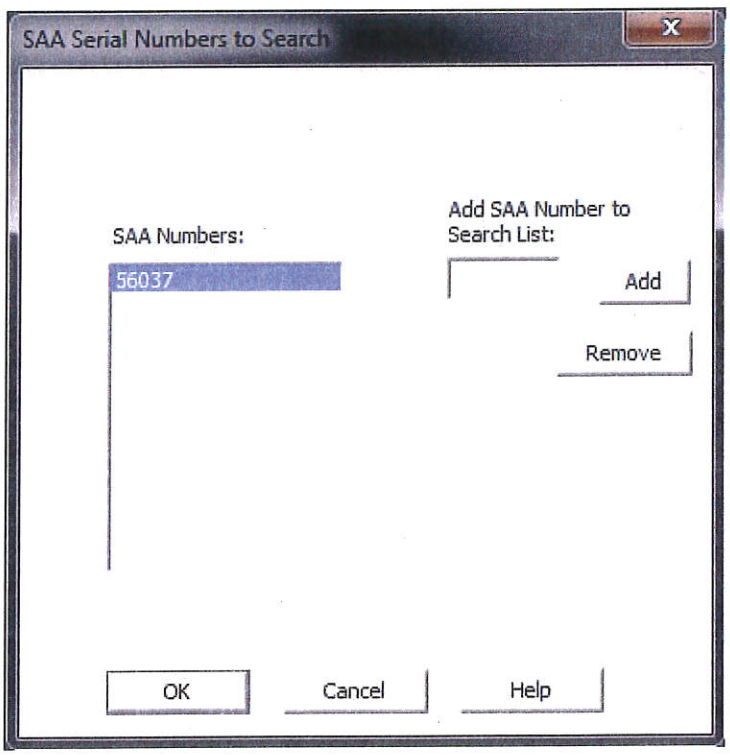


Figure 3.4: Enter the serial number of the SAA connected to the PC

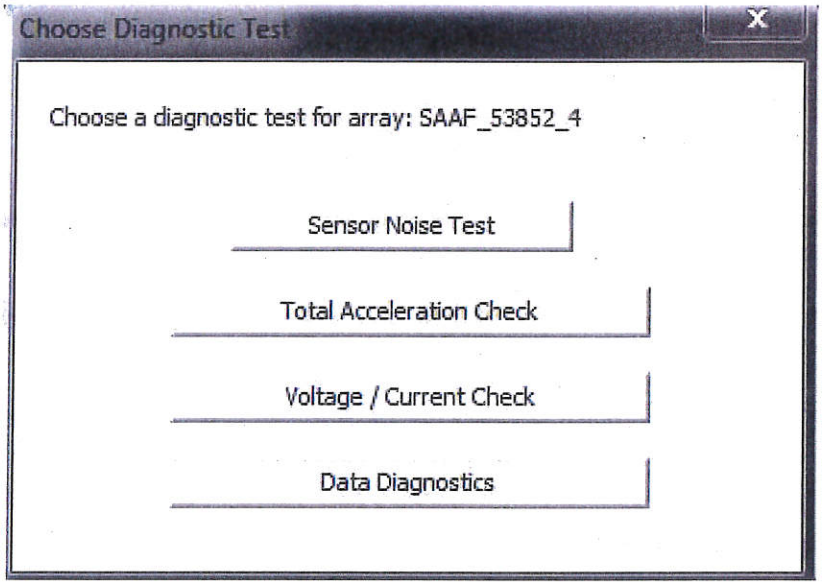


Figure 3.5: Diagnostics Tests window in SAARecorder.

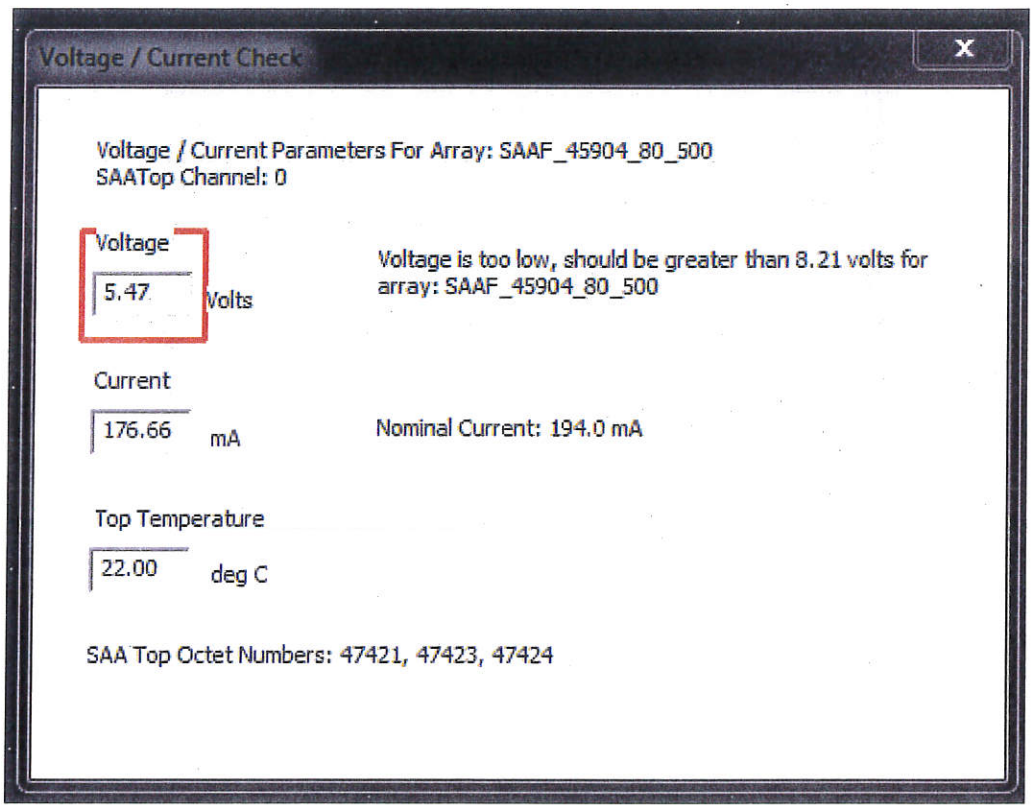


Figure 3.6: Voltage / Current Check for 7.3 m SAA with 900 m cable length

Typically, the voltage at the SAATop should be greater than 8.5V. If the voltage is too low, then the SAA will not return valid results. As shown in Figure 3.6, a warning will be given if the voltage is too low. Low voltages are typically a problem for long SAAs with long cables. In those cases it is recommended that the SAA be connected to an SAA232, an SAA232-5, or an SAA Field Power unit with voltage boost. The method for setting the voltage boost on an SAA232 or SAA232-5 is outlined in Appendix H. For more information on boosting the voltage on an SAAFPU, refer to the SAA Field Power Unit User Manual.

When the voltage check has been completed, it is recommended that the total accelerations for the SAA be checked as well. In the Diagnostic Tests window, click on 'Total Acceleration Check'. A plot showing the total acceleration levels for each segment appears (Figure 3.7). Verify that all values lie between 0.93 G and 1.07 G. If this is not the case, please contact Measurand for further diagnostic support.

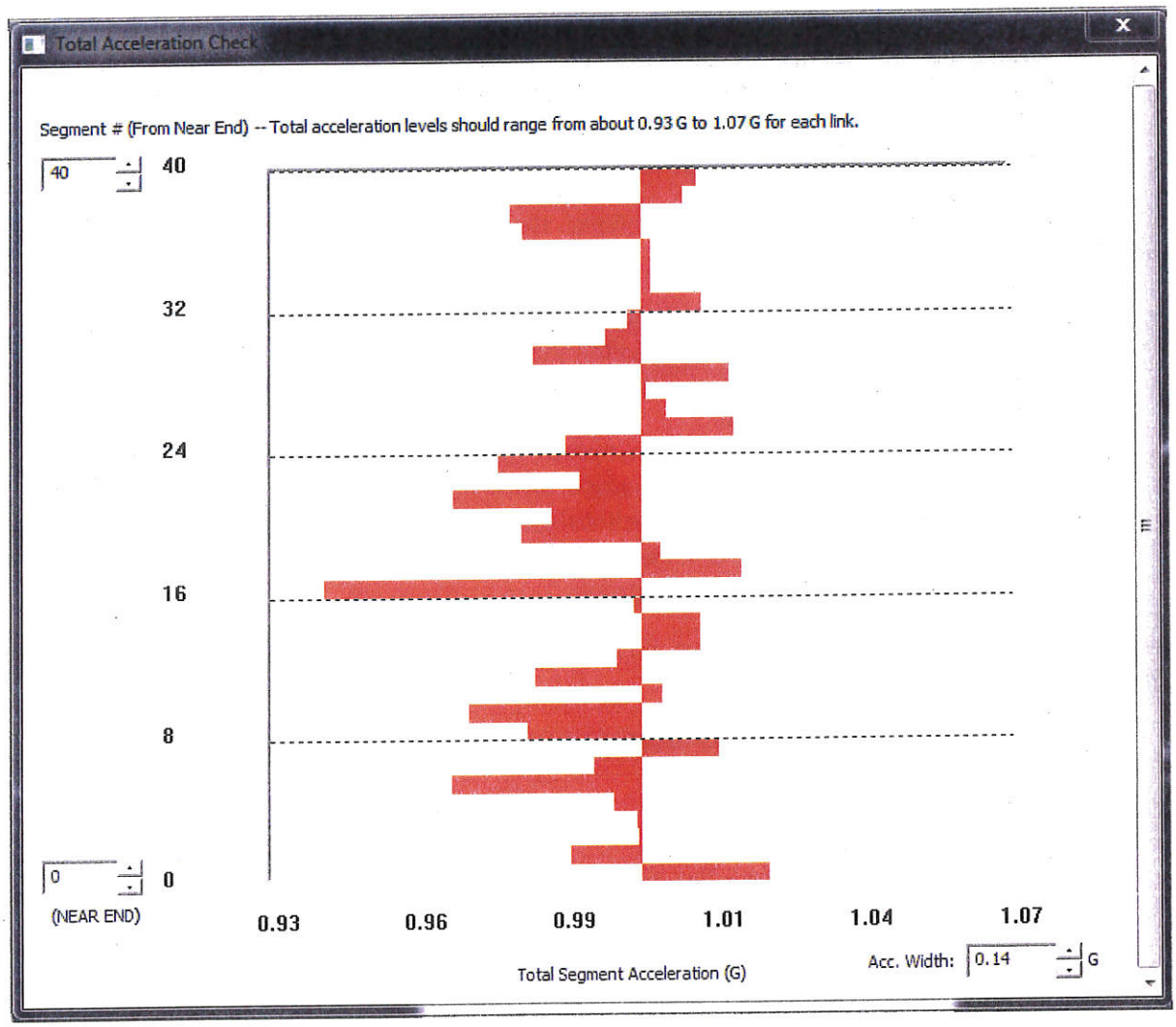


Figure 3.7: Graph for Total Acceleration Check in SAARecorder.

4. Installation

Installation of an SAA is straightforward if approved conduit is used and twist-prevention steps are followed. In order to make sure that the installation goes as smoothly as possible, it is important to be adequately prepared. This chapter outlines the basic safety considerations during installation, the supplies required during installation, the recommended installation methods for vertical and horizontal SAAs, and the steps for reeling an SAA for later re-use.

4.1 *Safety Considerations*

As with any other job, it is important to think about safety when installing an SAA. The following general safety precautions should be followed:

- Study the site carefully to anticipate and remedy any safety issues. For example, take precautions to keep the site free of obstructions or slippery areas.
- Take time to make sure everyone participating in the installation is being safe.
- Ensure all local codes are met and safety regulations are followed.

In addition to the general safety precautions listed above, it is recommended that the following potential hazards be considered:

- Stainless steel braid on SAAs can puncture the skin or damage the eyes.
- SAA reels are made of wood and are often sources of splinters.
- Facets on the reel are attached with staples. Both splinters and staples from the facets can cause punctures or scratches.
- PVC primer and cement are solvents which should be used in well ventilated areas.
- Epoxies used in splice kits should be used in well ventilated areas.
- Be careful when working around electrical conductors and batteries. Batteries can explode or cause serious burns if the terminals are shorted.
- Do not install SAAs during electrical storms.

Because of the potential hazards listed above, it is recommended that the following Personal Protective Equipment (PPE) be worn when installing SAAs:

- Heavy duty leather or puncture-proof gloves when working with the SAA or SAA reel
- Safety glasses with side shields
- Coveralls
- Steel-toed boots
- Rubber gloves when working with solvents
- Nitrile gloves when working with epoxy

4.2 *Proper Handling of SAA*

As with any other instrument, the SAA must be treated with care. Proper handling of the SAA will ensure a long life of the instrument and reliable results. Appendix A contains important details about proper handling of the SAA and SAA reel. These should be reviewed prior to handling the SAA. **SAAs which are not handled as discussed in the guidelines below and in Appendix A, will not be covered under warranty.**

4.2.1 General Guidelines

Please heed the following guidelines during the installation or retrieval of an SAA:

- Store the SAA on its reel when the SAA is not being used for monitoring.
- To minimize any twisting of the SAA, always go from reel to PVC conduit or from PVC conduit to reel, whether the PVC is on the ground or in a borehole.
- Keep the joints carefully aligned on the reel; roll it the same way each time. The on-reel dots should line up when properly reeled. Take pictures and notes to make sure you do this properly.
- Use a reel stand.
- Inspect the SAA for cuts or other damage before inserting it into the conduit.
- Remove sharp edges from the conduit before installing the SAA.
- Always lift the SAA at least 30 cm from the bottom of the conduit before rotating the SAA inside the PVC conduit. When rotating the SAA, pump the SAA up and down 10 cm to minimize friction and twist.
- Avoid any motions that will apply torque to a joint. The segment you move may not be the one that gets the torque, so think about the mechanical response along the SAA when applying a force or moment to it.
- **DO NOT** bend the joints beyond 45°. The only time bends greater than 45° are acceptable is when the SAA is stored on its reel.
- **DO NOT** pull on the communication cable. Pull on the PEX or the SAA itself.
- **DO NOT** exceed the maximum 320 kg force (700 lb) pull strength of the SAA.
- **DO NOT** exert more than 22 kg force (50 lb) of compressive force on the SAA when it is outside of conduit
- **DO NOT** exert more than 45 kg force (100 lb) on joints in 27 mm ID (1.049") conduit.
- **DO NOT** expose the protective coverings of the SAA to abrasion by dragging the SAA on the ground or running it over sharp edges.
- **DO NOT** move the joints more frequently than necessary.

4.2.2 Torsion Control and Joint Care

Note: When unreeling the SAA into the PVC conduit, allow it to turn freely. This will return the SAA to its factory "straight" state. If you are pulling the SAA into a pre-assembled PVC conduit, use a rope or a connector with a swivel to grab onto the eyelet at the far end of the SAA.

As previously discussed in 2.1.1 "Segments and Joints", the composite joint construction of the SAA is designed to minimize twist. Small amounts of twist will generally be recouped when the SAA is laid out on a smooth, flat surface or installed in a borehole, returning the SAA to a neutral or "factory" state. If the SAA is mishandled it is possible to twist the joints beyond their elastic limits. In this case, the SAA will not return to the factory state when the SAA is inserted into its PVC conduit. The best way ensure and verify a twist free installation is to use the SAA+PVC Installation described in Section 4.4.1.

4.2.3 Buoyancy Effects During Installation

A factor which must be considered during installation is the buoyancy of the PVC conduit. If the conduit is held from the top buoyancy typically cause the conduit to bend and form S-curves, making it difficult

to insert the SAA. In order to avoid the issues associated with buoyancy, it is recommended that you use the SAA+PVC Installation described in Section 4.4.1, using the weight of the SAA to keep the conduit straight.

If you must install the PVC conduit without the SAA, it is important to weight it down rather than allowing it to float up against a hard stop at the top. It is recommended that the SAA conduit be weighted down using chain. **Do not use water to weight down the conduit unless you remove the water before inserting the SAA into the PVC.** Though the SAA is built to withstand up to 10 bar of water pressure, it is best not to insert it into a PVC conduit which is full of water. If the conduit is filled with water, pushing the SAA into the water can create hydraulic pressures beyond the limits of the SAA waterproofing.

*Note: **Do not use water to weight down the PVC conduit.** Inserting the SAA into a small water-filled pipe can generate large hydraulic forces, causing a breach of the waterproof coverings.*

4.3 Supplies Needed for Installing SAA

4.3.1 Tools

When installing an SAA it recommended that the following tools be on hand:

- Hack saw or key hole saw
- Exacto knife or box cutter
- Tapping tools
- Pipe cutter
- PEX cutter
- PVC cement and primer
- Deburring tools for PVC
- Screwdrivers
- Measuring tape
- Markers
- Zip ties
- Duct tape
- Electrical tape
- Wire cutters
- Wire strippers
- Wire crimpers

4.3.2 Reel Stand

Always use a reel stand when reeling or unreeling an SAA. A smooth flow of the SAA into its conduit will ensure minimal twisting and flexing of the SAA joints. If the reel stand is omitted, unreeling and reeling will inevitably be jerky and uncontrolled.

A reel stand can easily be constructed using saw horses from the hardware store and a long sturdy metal bar. The weight of an SAA and its reel depend on the length of the SAA and the length of the communication cable attached to the SAA. Table 4.1 gives the weights of reeled SAAs for three common SAA lengths. Make sure that the materials used to construct the reel stand are sturdy enough to support the weight of the reel and SAA. Examples of various reel stands used for SAA installation are shown in Figure 4.1.

Table 4.1. Typical weights for reeled SAAs

SAA length (m)	Width of reel (m)	Weight of SAA and reel (kg)
30	0.4	43
65	0.8	77
100	1.1	113

Note: Weights given above do not include the weight for extra cable. Additional cable will increase the weight, make sure to use sturdy materials for the reel construction.

Figure 4.1: Examples of reel stands used in SAA installations. Note that the orientation of the reel on the reel stand depends on the type of installation done. For more information refer to Section 4.4.

Note: Reel stands should be able to support at least 227 kg (500 lbs) of weight. It is important that the bar supporting the reel is strong and rigid enough that it will not bend under the weight of the SAA, cable and reel. Schedule 80 1" steel pipe is sufficient.

4.3.3 Conduit

The SAA is designed to be installed into a 27 mm ID electrical conduit (Figure 4.2). This conduit is widely available throughout North America, and suitable replacements have been located in other regions. Measurand does not sell conduit for SAA installations. It is recommended that the customer select PVC conduit which either has bell ends or is connected using couplers, as shown in Figure 4.2. Threaded connections are not recommended as they can easily break during installation. The ID for the conduit shall be 27 mm ID +/- 1 mm. If the ID is smaller than 26 mm, you risk the SAA getting stuck. If the ID is larger than 28 mm, the SAA joints may not form a good contact with the conduit leading to reading errors.

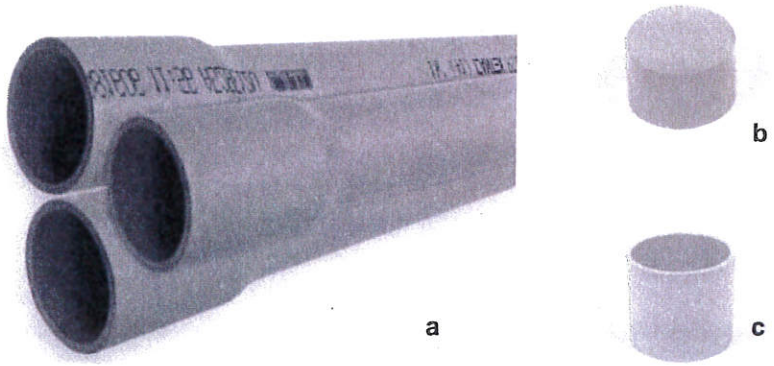


Figure 4.2: PVC conduit used as conduit for SAA. (a) 27 mm ID (1" trade dimension Schedule 40 PVC) electrical conduit with bell ends. (b) End cap. (c) Coupling for conduit without bell ends.

The approved conduit is normally used for electrical wiring. It can most easily be obtained from electrical supply stores, where it is almost universally available. It is not normally available as a "drilling" supply. Be sure to measure the ID of any conduit before using it. Do not rely on markings. Pipe and tubing sizes may be marked with "trade dimensions", which can cause further confusion. Please measure! If you have any questions regarding your conduit selection, please contact Measurand.

In general, the overall length of the joined PVC should be the same as the overall length of the SAA (see Section 2.1.1.6). Remember to account for the length of the PVC inside the coupler. For example, if the PVC conduit is purchased in lengths of 3 m (10') and the length of the coupler is 50 mm (2"), the actual length of each section of PVC is 2.95 m (9'10"), so for a 60 m (200') SAA you will need 21 pieces of PVC conduit, not 20. If the SAA will be installed at depth, you will need extra PVC conduit to bring the cable and extra PEX to the surface.

*Note: **DO NOT install SAAs without a conduit!** **The conduit is a key component in allowing the SAA to monitor deformations over a long period of time.***

An end cap is mandatory for the bottom of the conduit, to keep the joints snugged and to prevent water ingress. In cases where the conduit does not have bell ends, you will also need to provide couplings. Examples of both end caps and couplers are shown in Figure 4.2b and Figure 4.2c, respectively.

Note: The PVC conduit used for SAA installation is very flexible. Tests have shown that deflection per applied load for the PVC conduit is approximately 10 times greater than for standard inclinometer conduit.

To assemble the conduit, you will need to use a PVC primer and cement. The primer helps to soften the PVC making it easier for the PVC Cement to weld the two pieces together. This is particularly helpful in cold weather conditions when the chemical weld reaction may be impacted by the temperature. Selection of the PVC primer and cement depend on the temperature and acceptable setting times. Check the manufacturer's specifications to find information regarding set times vs. temperature. All-

weather quick set cements tend to set in less than 10 minutes for temperatures between -20°C and 30°C (-5°F and 90°F), but you must verify the temperature ratings and set times. Make sure to follow the manufacturer's instructions for the product you plan to use.

Note: It is important to follow the PVC Primer and Cement manufacturer's recommendations for set times and temperature ratings. The most common cements may fail at low temperatures. Choose products which are suitable to the environment and weather you will be encountering.

4.3.4 Chain

Chain can be used to weigh down conduit if the PVC conduit must be installed before the SAA is on site. The chain will pack down inside the PVC conduit, so it is important to buy a length of chain which is longer than the PVC conduit into which it will be inserted. The packing ratio is approximately 1.5:1, so for every 1 m of PVC conduit, you will need 1.5 m of chain. When purchasing chain, look for chain with properties as described in Table 4.2. The chain below is nominal "3/4 inch" chain. If in doubt, fill a 3 m (10') length of vertical PVC conduit with chain and verify that it can be removed without snagging.

Table 4.2: Material properties and approximate dimensions for chain used to weigh down PVC conduit

Material	Steel
Finish:	Zinc plating
Inside link length:	25 mm (1")
Inside link width:	10 mm (0.4")
Material diameter:	5.5 mm (0.2")
Weight:	0.6 kg/m (0.4 lbs/ft)

4.3.5 SAA Install Kit

The SAA Install Kit includes various parts which make preparing for SAA installation more convenient, and which produce a secure installation in less time. The PVC fittings in the kit (referred to as the top stack) surround the PEX at the cable end of the SAA. A blunt-nose setscrew threaded into the fittings holds a vertical SAA at its set azimuth while maintaining axial compression to snug the joints, and provides a secure hold at the cable end of horizontal SAAs. The top stack helps keep surface water out of the 27 mm ID PVC conduit holding the SAA, and help prevent outside forces and moments from being applied to the SAA. Use of the kit replaces the previous method used for compressing the SAA joints inside the conduit (cutting slots, and using gear clamps to secure the SAA). A photo of the top stack is included in Appendix I.

Two versions of kit are available: one with selected tools, and one without any tools. The kit is recommended for vertical or horizontal installations. It is possible to make your own installation kit using fittings specific to your conduit. In this case, use the instructions provided in Appendix I as a guideline for materials required to produce your own installation kit.

4.3.6 PEX and PEX Extension Kit

The PEX Extension Kit includes 5 PEX couplers with stainless steel braid, 20 PEX crimp rings, and a crimping tool. Clients can either source additional ¾" PEX locally, or buy it directly from Measurand. The PEX couplers provided in the kit are designed to provide a solid mechanical connection to hold the

weight of the SAA, and to resist any twist at the PEX connection; something that traditional PEX couplers cannot do. It is possible to purchase sets of 5 PEX couplers and 20 PEX crimp rings without the crimping tool, contact Measurand for more details. The items required to extend the PEX tubing on the SAA are shown in Figure 4.3.

For instructions on when to use a PEX Extension Kit, please refer to Sections 4.4.1.3 and 4.4.2.3. Instruction on how to use the PEX Extension Kit are provided in the PEX Extension Kit Manual included with the kit.

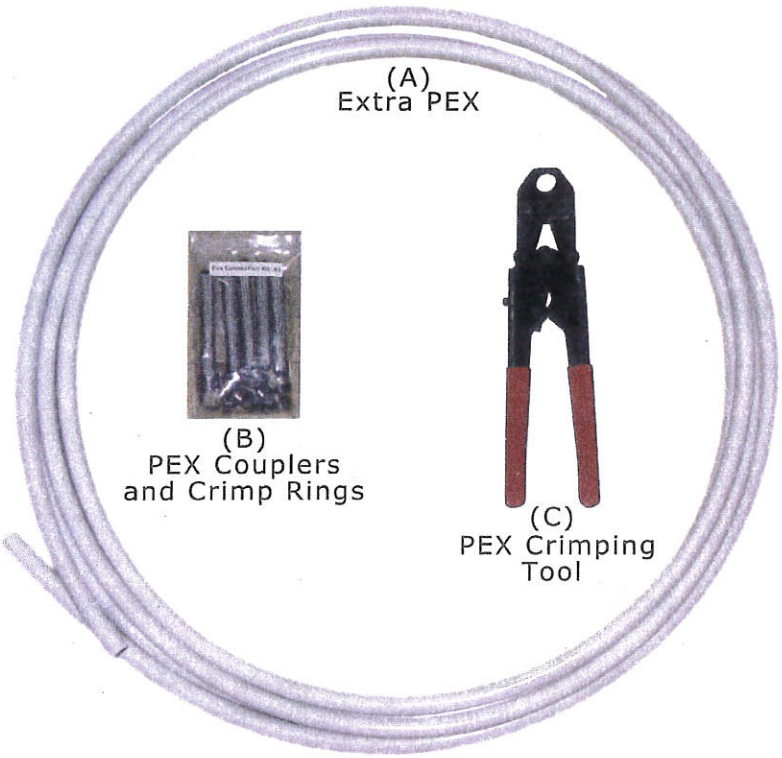


Figure 4.3: Items required to extend PEX on SAA. (A) extra ¾" PEX tubing obtained at plumbing supply store, (B) Measurand PEX couplers and crimp rings, (C) PEX crimping tool.

4.4 *Recommended Installation Methods for Vertical to Subvertical Installations*

There are two recommended methods for installing the SAA. The first is the method referred to as SAA+PVC installation. This method is the best way to install an SAA as it will reduce the possibility of twisting the joints. The method requires space to set up the SAA and PVC, so it cannot always be used.

The second method involves installing the PVC conduit, then later inserting the SAA. This method will be discussed in detail in "Installing SAA Directly Into a PVC Cased Borehole" in Section 4.4.2.

4.4.1 SAA+PVC Installation

Prior to attempting installations of SAA, view the SAA Installation with PVC video at: http://measurandgeotechnical.com/support_saa_tutorial_videos.html. The processes used for SAA+PVC installation are shown in Figure 4.4.

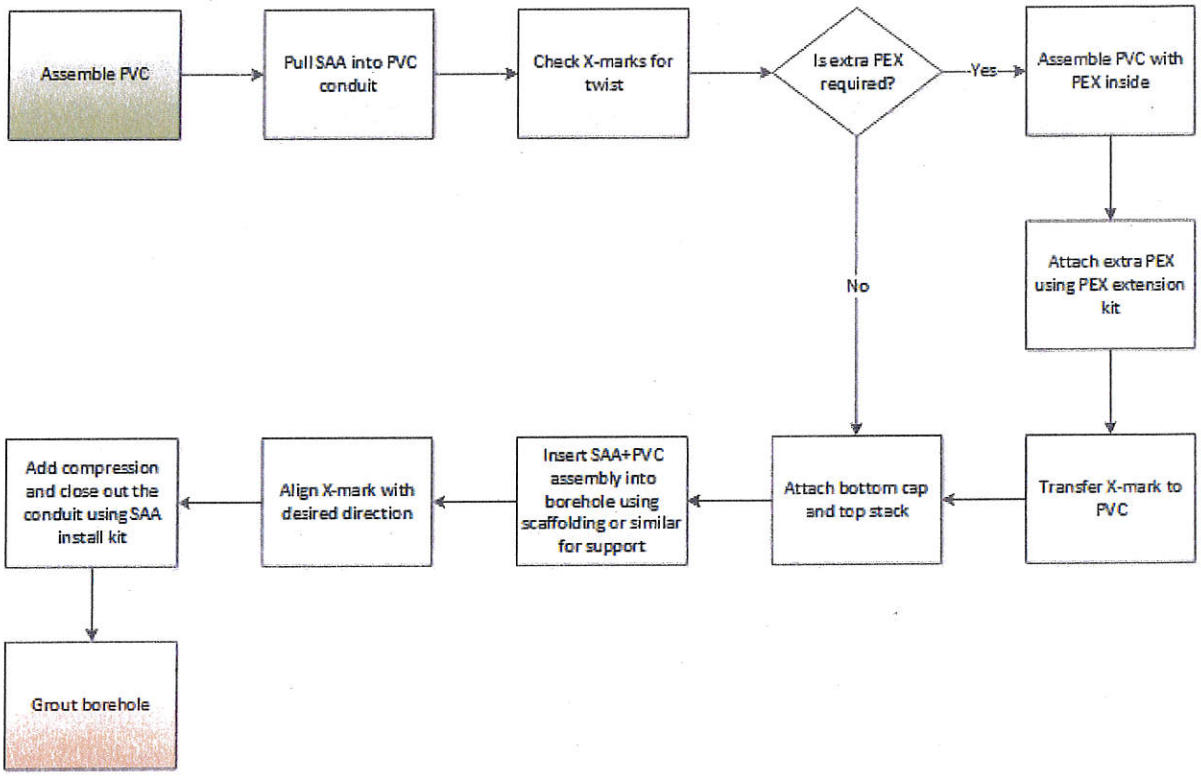


Figure 4.4: Work flow for installing SAA using SAA+PVC installation method

4.4.1.1 Assembling PVC Conduit for SAA+PVC Installation

All PVC conduit ends should be kept clean from dust, oil, snow. Look inside the PVC pipes to make sure that no foreign objects are inside the PVC pipe. The edges of conduit over which the SAA is being installed should be smoothed using a deburring tool to prevent abrasion.

Note: When using SAA+PVC method, you will have to pull the SAA until at least two segments are out of the bottom of the conduit. This is to help check for twist using the X-Marks on the PEX and at the bottom of the SAA. Glue all the PVC pieces but one. This piece will be added on after the X-Marks have been checked.

In order to minimize the handling of the SAA+PVC assembly prior to insertion into the borehole, lay out the PVC sections so that the bell ends are away from the borehole. If you are using rope to pull the SAA into the PVC, **make sure to pull the rope through all PVC sections before gluing these together**. The SAA Install kit includes a wire to enable fishing a rope through each section of PVC.

When gluing the PVC using PVC primer and cement, make sure to follow the manufacturer's instructions for the product you plan to use.

Note: It is important to follow the PVC Primer and Cement manufacturer's recommendations for set times and temperature ratings. The most common cements may fail at low temperatures. Choose products which are suitable to the environment and weather you will be encountering.

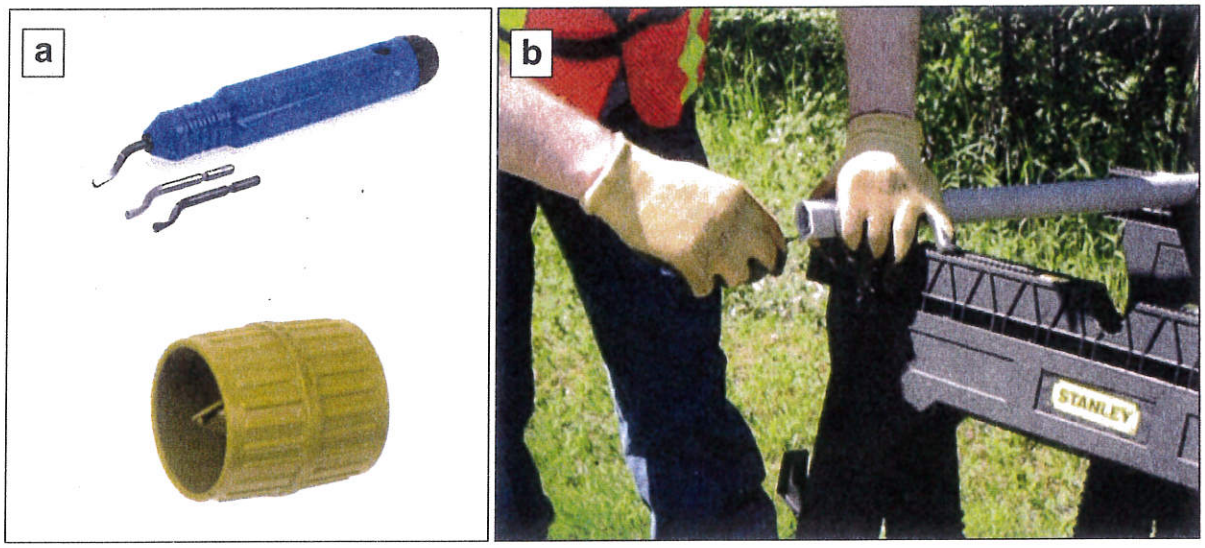


Figure 4.5: Deburring the PVC. (a) Typical PVC deburring tools. (b) Example of deburring, note that both the inside and outside edges are to be deburred.

It is a good practice to tape the joints of the PVC conduit after gluing them together. This is to make sure that the joints are not pulled apart before fully setting.

If you do not need to add any extra PEX to the SAA, glue the bottom part of the top stack included in the SAA Install Kit to the top of the PVC conduit at this time.

4.4.1.2 Pulling the SAA Into the PVC Conduit

Prior to pulling the SAA into the PVC make sure that the conduit is straight, this is essential to pulling the SAA into the conduit.

At this time, place the SAA reel on the reel stand so that the SAA unreels from the bottom (Figure 4.6a). Once this is done, pull the rope through the eyelet and secure with electrical tape (Figure 4.6b). It is also possible to use a cable fishing tool to pull the SAA. However, if you opt to use one, use a swivel connection between the SAA and the cable fishing tool to allow the SAA to freely rotate during the pulling process. When ready, pull the SAA into the conduit, making sure that there is someone on hand to guide the SAA into the conduit (Figure 4.6c). Keep pulling the SAA until one or two segments are completely out the far end of the conduit (Figure 4.6d).

After the SAA is pulled into the conduit, check the X-marks at the near and far ends to make sure that they are aligned, if the X-mark is located on the underside of the SAA, lift the bottom segment to verify the alignment. **Do NOT turn the SAA inside the PVC, this could induce twist**.

Once you have confirmed that there is no twist in the SAA, push a piece of PVC conduit which has been cut to length over the eyelet end of the SAA and glue it in place. Also glue the end cap in place at this time. It is good practice to tape these joints in order to support them while the cement sets.

If you need to extend the PEX and are using a PEX extension kit, transfer the X-marks onto the PVC conduit in order to help align the SAA inside the borehole.

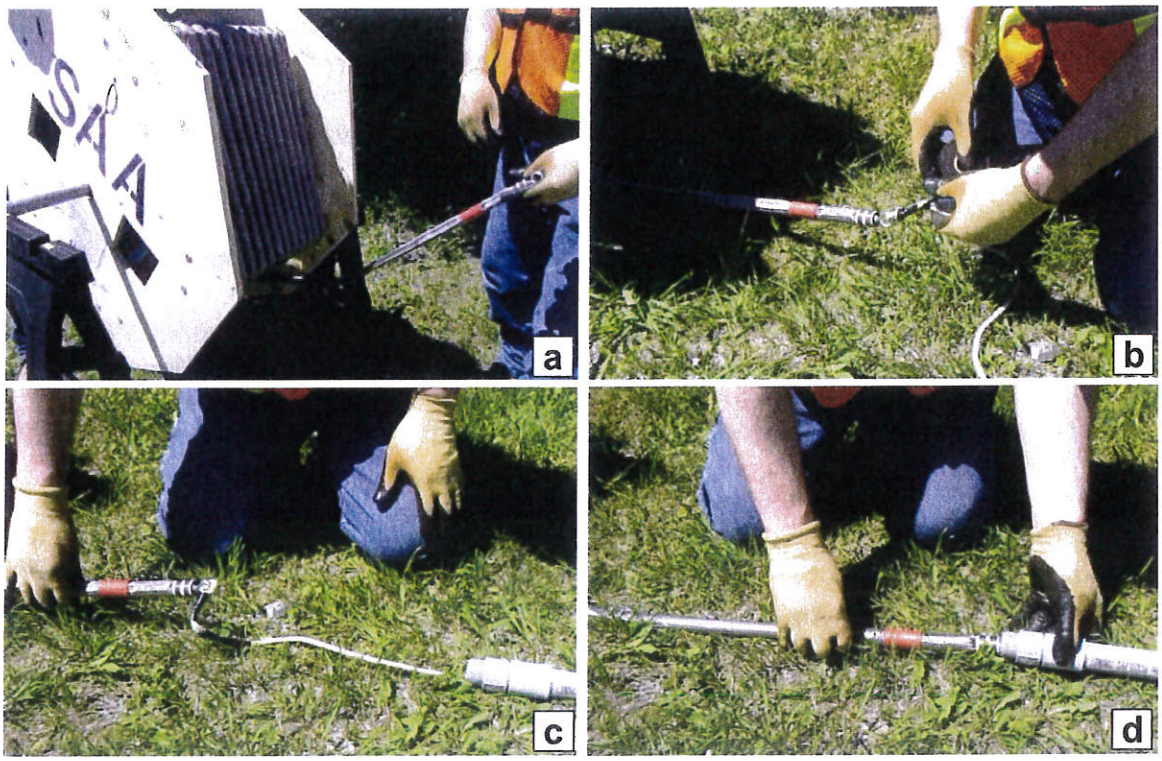


Figure 4.6: Pulling SAA into PVC conduit.

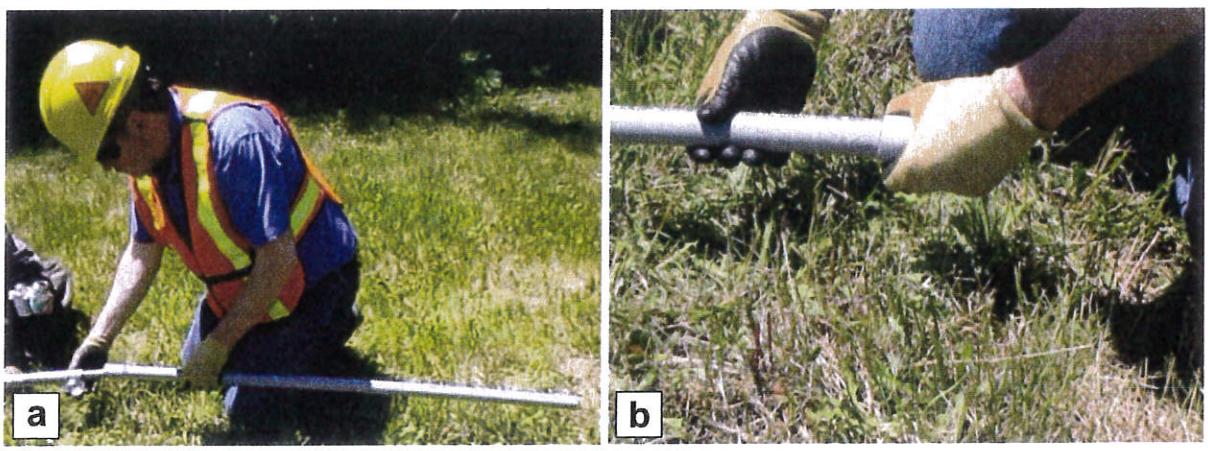


Figure 4.7: Closing the far end of the PVC conduit.

4.4.1.3 Extending PEX for an SAA+PVC Installation

Standard SAAs come with 1.5 m (5') of PEX tubing attached at the top. In some cases, it may be necessary to extend the PEX tubing. In these cases, it is recommended that the PEX extension be done using the following procedures. When extending the PEX, use the methods described in the PEX Extension Kit Instruction Manual included with the kit.

In the case where less than 3 m of PEX is being added, it is recommended that the additional PEX be purchased in straight pieces. When using straight pieces, the X-mark can easily be transferred to the extra PEX piece using a straight edge and an exacto knife.

In most cases, the length of PEX being added is greater than 3 m, and it is easier to use PEX which has been reeled up as shown in Figure 4.3. In this case, it is better not to rely on the PEX for setting the azimuth of the X-mark. Instead, use the PVC conduit, which resists torsion for this purpose. The PEX will still be used to apply axial compression form the top. Please follow this procedure:

1. Lay out and assemble PVC conduit so that it is approximately the same length as the additional PEX.
2. Push the PEX into the PVC conduit. The PVC conduit will help straighten out the PEX tubing, making it easier to feed the SAA cable through the PEX.
3. Use a cable fishing tool to pull the SAA cable through the PEX. Make sure that the crimp rings and coupler are placed between the two pieces of PEX to be attached (Figure 4.8a)
4. Make sure to mark the X-mark on the PVC conduit containing the SAA. (Figure 4.8b)
5. Connect the PEX tubing using the methods described in the PEX Extension Kit Instruction Manual. (Figure 4.8c)
6. Glue the PVC conduit pieces together. (Figure 4.8d)
7. Mark the X-mark on the PVC containing the PEX for later use during the alignment procedure.
8. Attach the bottom half of the top stack included in the SAA Install Kit to the top of the PVC conduit.

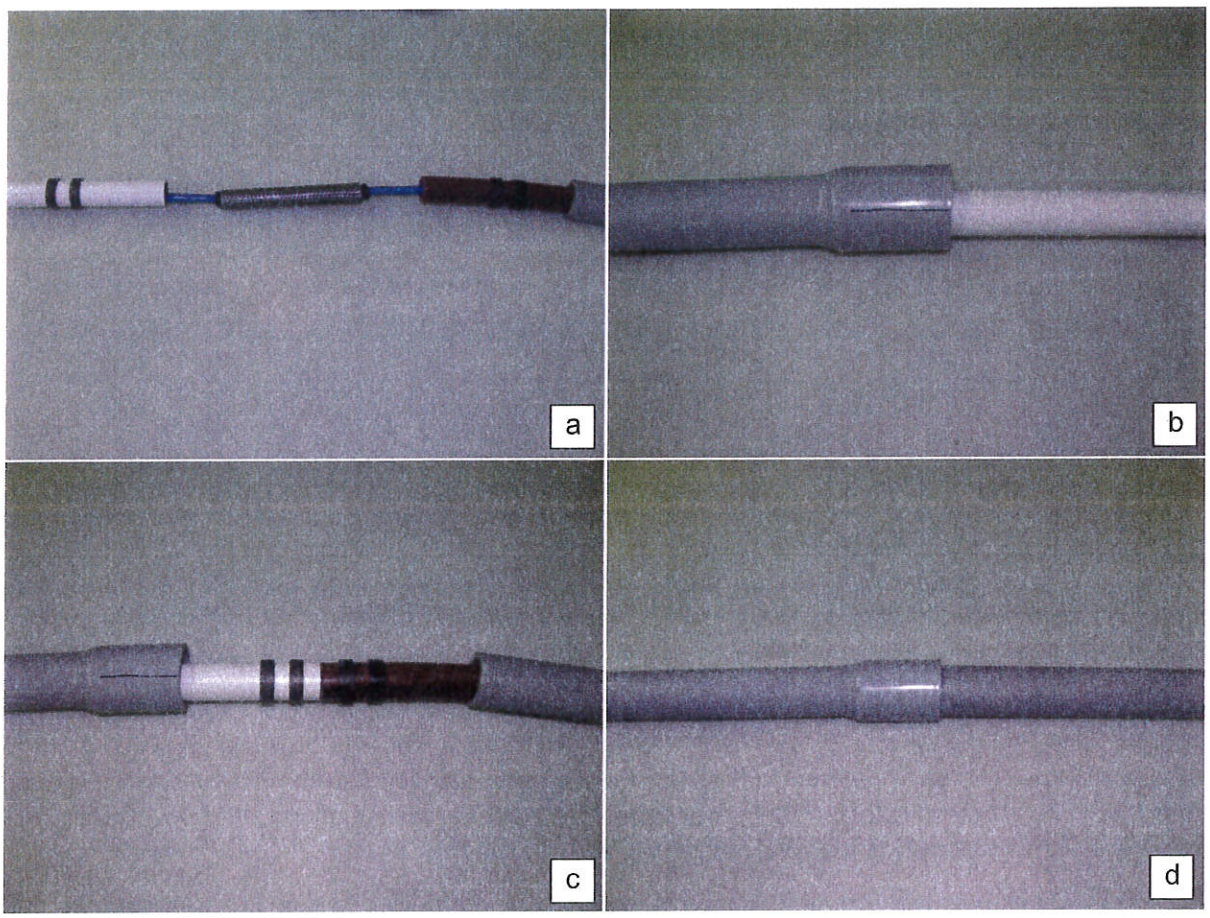


Figure 4.8. Extending PEX for SAA+PVC installations

4.4.1.4 Inserting the SAA+PVC Assembly Into the Borehole

Prior to inserting the SAA+PVC assembly into a borehole it is a good idea to tighten the set screw in the top stack. If this is done, the SAA will not move inside the PVC during the insertion process.

When inserting the SAA+PVC assembly into the borehole, you will need to support the assembly in order to maintain the minimum recommended radius of 3.5 m (11.5') for 500 mm segments, and 3 m (10') for 305 mm segments. If a smaller radius is used, it is likely that segments will be bent, which will lead to errors in measurement, and could also damage in-SAA circuitry. Any equipment which can offer two points of support to the SAA+PVC assembly can be used. Examples of on-site equipment are shown in Figure 4.9. These examples include: a) scaffolding, b) bulldozer, and c) drill rig and derrick. The supports should be wide enough or include side posts so that the SAA+PVC cannot slip off sideways. Teamwork and communication are key for making sure that the insertion process goes smoothly. Make sure helpers avoid abrupt pushes and uncoordinated movements. Discuss the sequence with all involved before starting the insertion.

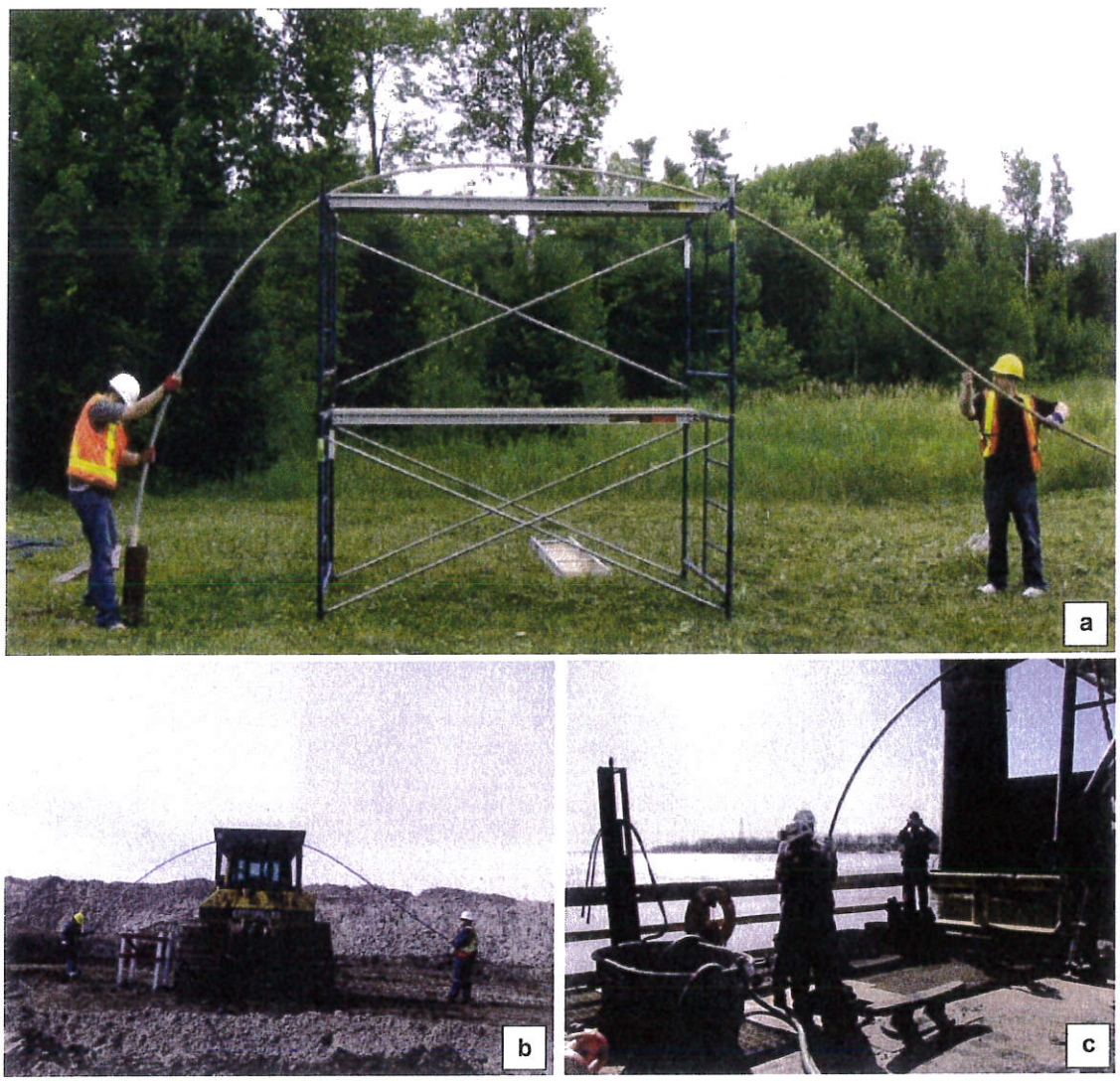


Figure 4.9: Inserting SAA+PVC assembly into borehole using various equipment available on site to support the assembly.

For long SAAs (length >50 m or 165') it is a good idea to use a winch and cable to lower the SAA+PVC assembly. The cable should be attached near the bottom of the assembly to help control the descent of the assembly into the borehole. A tight loop of cable held by a cable clamp and secured to the PVC with gear clamps is recommended. A rope may be used instead of a cable if it is large enough for the load, and abrasion is avoided. Please take precautions to avoid any hand damage from cables or ropes, and falling objects. The hanging fixture supplied in the SAA Install Kit (Figure 4.10) may be used to hold the SAA temporarily at an elevation, should the insertion need to be paused.

Note: If the SAA is being inserted into an existing inclinometer conduit, it is recommended that a tremie tube be attached to the SAA+PVC assembly before lowering the assembly into the conduit. Another option is to do displacement grouting.

In most cases it is recommended that the borehole into which the SAA will be installed be over-drilled. This way the SAA+PVC assembly can hang in the borehole which will lead to the PVC and SAA being as straight as possible. In order to help support the SAA during the grouting process, fasten the hanging fixture supplied in the SAA Install Kit to the top of PVC (Figure 4.10).

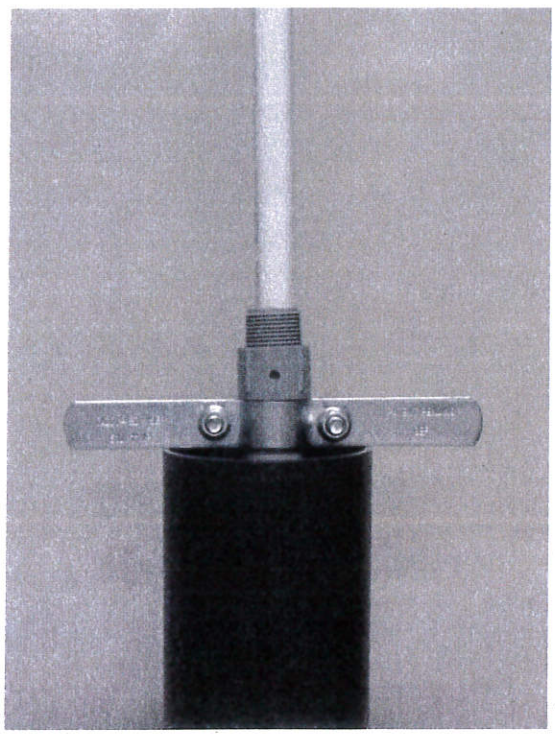


Figure 4.10: Using hanging fixture to provide support to SAA+PVC

4.4.1.5 Aligning the X-Mark in the Desired Direction

Raise the PVC approximately 30 cm so that it is not sitting on the bottom of the borehole. It should be able to rotate freely in the conduit. Pump it up and down while turning it. If the PVC does not move freely **DO NOT FORCE IT!** Leave the SAA+PVC as it is and take a reading of its azimuth offset (degrees relative to the intended direction). This offset can be cancelled in the converter or viewer software, to rotate the data to the intended azimuth.

Figure 4.11: Lifting and aligning the SAA+PVC using the hanging fixture.

Once the PVC is able to freely rotate, turn the PVC so that the X-mark is pointed in the desired direction (e.g. downslope). Once you have done this, lower the PVC to rest on the hanging fixture. At this point it is possible to complete installation by following the directions outlined in Section 4.4.3.

4.4.2 Installing SAA Directly Into a PVC Cased Borehole

In some cases, it is not possible to lay out the PVC on the ground and assemble it for the SAA + PVC installation. In these cases, the PVC will need to be assembled and lowered downhole prior to inserting the SAA. This installation method is susceptible to buoyancy effects and care must be taken to avoid sinuating the PVC prior to installing the SAA.

Note: If a PEX extension longer than 3 m (10') is used from the top of an SAA to surface level, and/or the SAA length is over 10 m, every effort should be made to use the SAA+PVC installation method described in Section 4.4.1. It provides superior azimuth control and no-twist verification.

*Note: **Do not rest the conduit on the bottom of the borehole.** In order to make sure to avoid sinuating the PVC conduit, over-drill the borehole at approximately 0.5 m beyond the expected length of the SAA and conduit. Use a hanging fixture such as the one provided in the SAA Install Kit to keep the conduit suspended in the borehole.*

For assured success in all installations, the 27 mm PVC conduit must be weighted to keep it straight. Two recommended methods for weighting the PVC conduit are:

1. Put the SAA in the PVC before grout is inserted into the borehole. For conduits over 30 m in water, the buoyancy effects may be high enough to make insertion of the SAA into PVC conduit difficult. In these cases, it is recommended that you use the method described below to weight the conduit during the grouting process.

2. If the SAA is not available, use steel chain as described in Section 4.3.4 to completely fill the PVC conduit. Test a 3 m (10') length of conduit with chain to ensure that the chain will not snag in

the conduit. The chain will pack in the conduit, therefore bring enough chain to overfill the conduit by 50%.

*Note: **Do not use water to weigh down the PVC conduit.** The water will make it difficult or impossible to insert the SAA into the PVC since the hydraulic forces will cause the self-snugging joints of the SAA to compress. If the joints block the water egress, the attempt to insert the SAA **could lead to hydraulic pressures beyond the pressure ratings of the SAA protective coverings.***

Once the SAA or chain in is the conduit, it is possible to grout the conduit into the borehole. The most commonly used process for installing the SAA directly into the PVC cased borehole is shown in Figure 4.12.

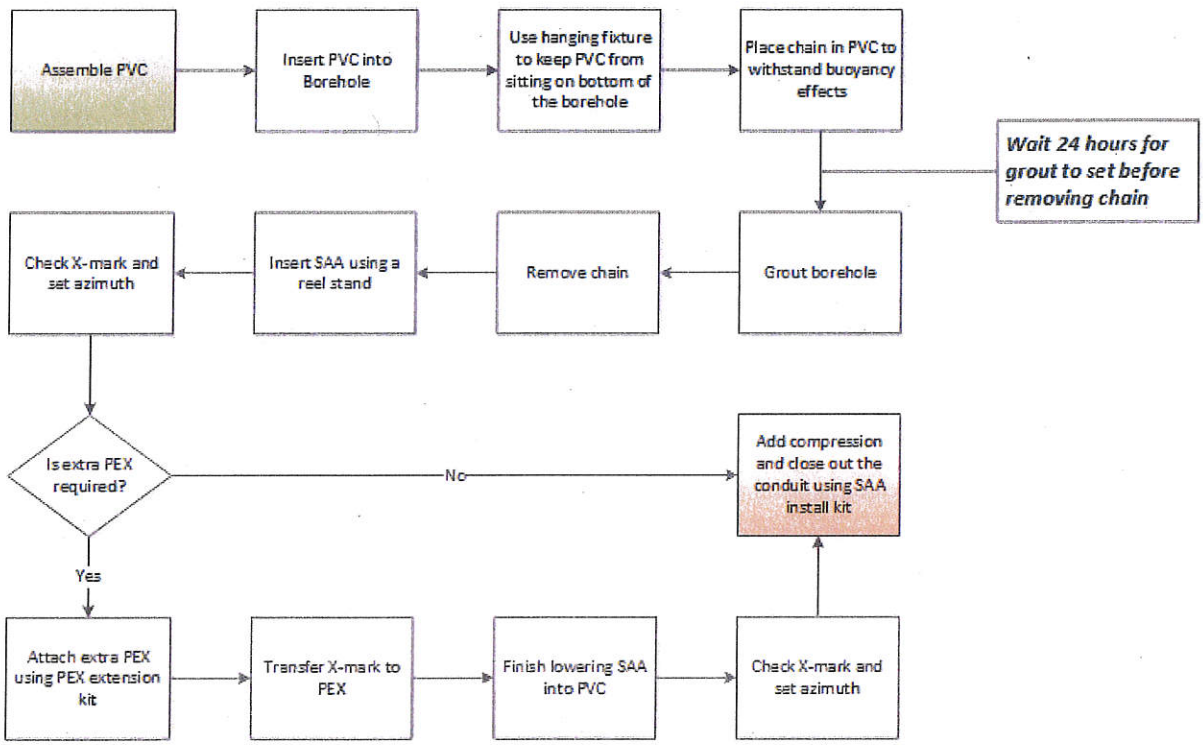


Figure 4.12: Work flow for installing SAA into a pre-cased borehole.

4.4.2.1 Assembling PVC Conduit

All PVC pipe ends should be kept clean from dust, oil, and snow. Look inside the PVC pipes to make sure that no foreign objects are inside the PVC pipe. The edges of conduit over which the SAA is being installed should be smoothed to prevent abrasion using a deburring tool as shown in Figure 4.5.

When gluing the PVC using PVC primer and cement, make sure to follow the manufacturer's instructions for the product you plan to use.

Note: It is important to follow the PVC Primer and Cement manufacturer's recommendations for set times and temperature ratings. The most common cements may fail at low temperatures. Choose products which are suitable to the environment and weather you will be encountering.

It is highly recommended that the joints of the PVC conduit be taped after gluing them together. This is to make sure that the joints have enough time to set properly before being inserted into the borehole.

The easiest method to use is to assemble the PVC conduit as you lower it into the borehole. Start by gluing and taping the end cap onto the bottom most piece of PVC before inserting it into the borehole. Lower the first piece of PVC conduit then glue the next piece on and tape the joint as shown in Figure 4.13. Due to buoyancy effects, you will need a helper to hold the pieces in place while you work, as shown in Figure 4.13a. Keep adding more conduit, gluing and taping each joint, until you have assembled the required length of conduit.

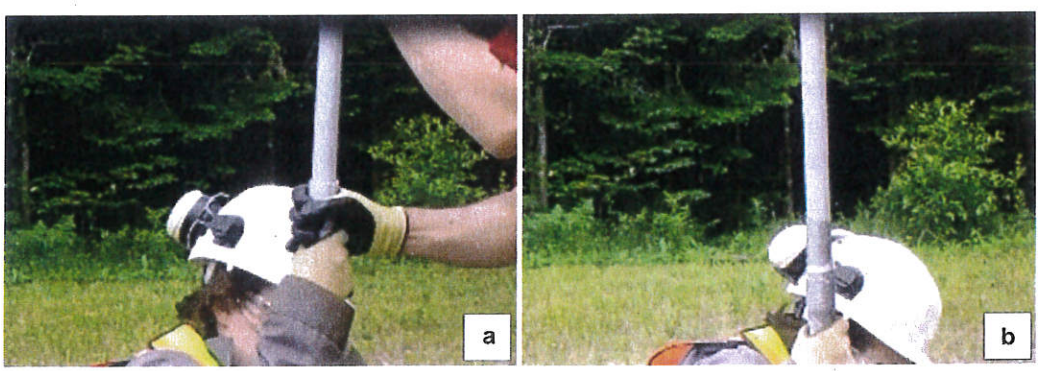


Figure 4.13: Assembling PVC conduit downhole.

Glue the bottom part of the top stack included in the SAA Install Kit to the top of the PVC conduit at this time.

Note: Use the hanging fixture included in the SAA Install Kit to help keep the conduit off of the bottom of the borehole. It is also possible to use the fixture to apply downward force on the conduit, before the conduit is weighted down with chain or SAA.

Insert the chain into the PVC conduit as shown in Figure 4.14. See Section 4.3.4 for chain recommendations. Make sure to insert chain straight down into the conduit. Otherwise you run the risk of causing wear on the PVC fitting at the top.

Figure 4.14: Inserting chain into PVC conduit.

Grout the SAA using the mix recommended in Section 4.4.4.

Note: The grout will take 24 hours to set. The SAA should be inserted after the grout has set. Do NOT remove the chain from the PVC conduit before 24 hours have passed.

4.4.2.2 Inserting SAA Into a Pre-Cased Borehole

Once the grout has set, it is possible to remove the chain from the conduit and proceed with inserting the SAA directly into the conduit.

Start by setting the SAA reel on the reel stand so that it unreels from the top, as shown in Figure 4.15. The reel should be placed close to the borehole in order to avoid having too many unsupported segments in the air. Unsupported segments can easily be twisted inadvertently.

The insertion should be done by two people, as shown in Figure 4.15. One person guides the SAA into the borehole while the second person controls the rate of descent by carefully handling the reel. It may be necessary to have more helpers when dealing with longer SAAs. Teamwork and communication is key for making sure that the insertion process goes smoothly. Avoid jerking the SAA forward off the reel which will stress the joints.

Figure 4.15: Inserting SAA into a pre-cased borehole.

4.4.2.3 Extending the PEX for a Pre-Cased Borehole

As discussed earlier, standard SAAs come with 1.5 m (5') of PEX tubing attached at the top. In some cases, it may be necessary to extend the PEX tubing. In these cases, it is recommended that the PEX extension be done using the following procedures.

In the case where less than 3 m of PEX is being added, it is recommended that the additional PEX be purchased in straight pieces. When using straight pieces, the X-mark can easily be transferred to the extra PEX piece using a straight edge and an exacto knife or fine tipped marker.

In most cases, the length of PEX being added is greater than 3 m, and it is easier to use PEX which has been reeled up as shown in Figure 4.3. In this case, it is difficult to place the X-mark on the extra PEX. Instead, it is recommended that the following procedure be used to prepare the PEX connection:

1. Tap an extra set-screw into the top stack included in the SAA Install Kit. The extra set screw should be located on the opposing side of the top stack vis-à-vis the existing set-screw location. This extra set-screw will help provide mechanical support for the SAA during the PEX extension process.
2. Align the X-mark on the SAA so that it is pointed in the desired direction. Follow the directions provided in Section 4.4.2.4.
3. Tighten both set screws in order to hold the SAA in position during the PEX extension process.
4. Connect the extra PEX to the SAA using the procedures outlined in the PEX Extension Kit Instruction Manual.
5. Transfer the X-mark onto the PEX tubing.
6. Making sure to have a good hold of the SAA, loosen the two set screws.
7. Carefully lower the SAA into the PVC conduit making sure not to turn it during the lowering process.
8. Once the SAA touches the bottom of the PVC conduit, seal the conduit using the methods outlined in Section 4.4.3.

4.4.2.4 Aligning the SAA Inside the PVC Conduit

In this installation method, the PVC conduit cannot be used to align the SAA so that the X-mark is pointed in the desired direction. Instead the SAA must be moved inside the PVC. Raise the SAA approximately 30 cm so that it is not sitting on the bottom of the conduit. It should be able to rotate freely in the conduit. Pump it up and down while turning. If the SAA does not move freely DO NOT FORCE IT! Leave the SAA as it is and take a reading of the azimuth offset (degrees relative to the intended direction). This offset can be cancelled in the converter or viewer software, to rotate the data to the intended azimuth.

Note: If the conduit is sinuated or ovalized, the SAA will not be able to rotate in it freely. In these cases, it is best to mark the X-mark on the conduit and survey its azimuth. The azimuth can then be applied in software so that all movements are shown to act in the same direction.

If the SAA is able to rotate freely, turn the SAA so that the X-mark is pointed in the desired direction (e.g. downslope). Remember to pump the SAA up and down as you are turning it to ensure it is free in the conduit. Once you have done this, lower the SAA to rest on the bottom of the PVC conduit. At this point it is possible to complete installation by following the directions outlined in Section 4.4.3.

4.4.3 Finishing the Installation Process Using the SAA Install Kit

It is recommended that the SAA Install Kit be used during the installation process. This kit was designed to help make the installation process easier. The kit includes fittings which improve the installation process by providing a more secure way to compress the SAA.

If you have followed the steps outlined in Sections 4.4.1 and 4.4.2, the installation should look similar to Figure 4.16a. At this point, in order to finish the installation, you will need to apply compression to the SAA. This will cause the joints to expand and snug into the conduit. In order to complete the installation process, follow the steps outlined below.

1. Apply downward force of no more than 45 kg (100 lbs) on the PEX and turn the set screw on the top stack to maintain compression and orientation of the SAA within the PVC. (Figure 4.16b)
2. If you have not already done so, mark the X-mark on outside the PVC pipe for future reference.
3. Cut away any excess PEX tubing. (Figure 4.16c)
4. Thread the top portion of the pre-assembled top stack over the cable and screw it into the bottom portion. Tighten the gland at the top of the top stack until the rubber gasket seals the cable. (Figure 4.16d)
5. Run cable to the earth station. Use conduit to protect the cable and to ease cable replacement if required. (Figure 4.17a). Since the PVC conduit containing the SAA has been sealed, it is not necessary for the flexible conduit to cover the entire cable. If the top of the SAA is protected using a well head covering or some other buried structure, it is possible to use zip ties provided in the kit to hold the conduit in place under the protective conduit (Figure 4.17a). It is also possible to do cable splices or attach items such as the SAASPD surge protection device at this point (Figure 4.17b).

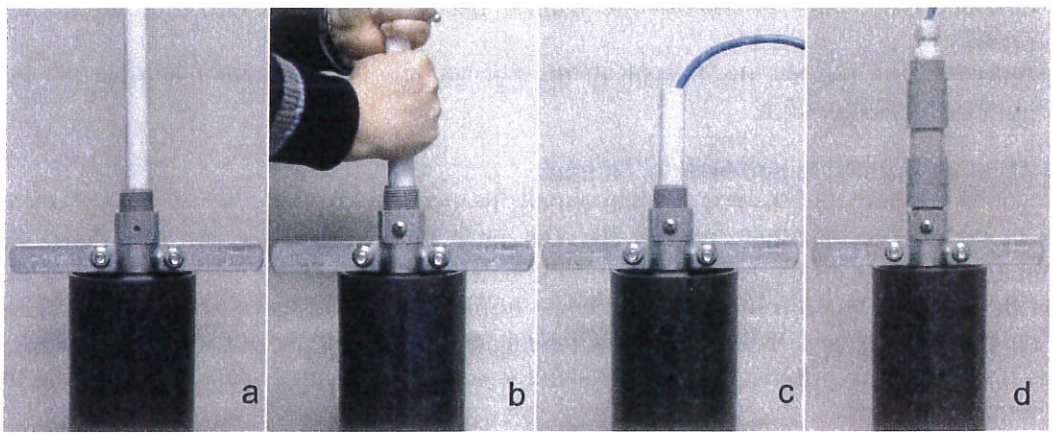


Figure 4.16: Using the pre-assembled top stack during SAA installation to complete the installation process.

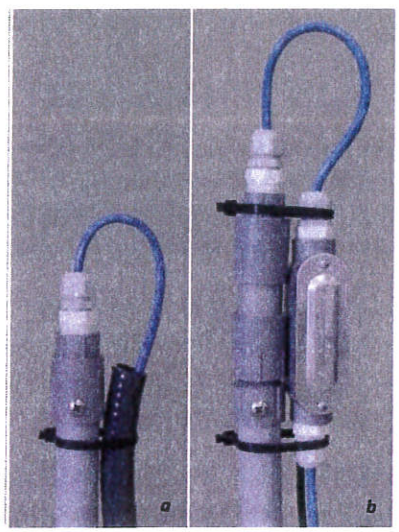


Figure 4.17: Finishing off SAA installation under a protective well head. (a) Attaching flexible conduit to PVC conduit using zip ties. (b) Attaching SAASPD at top of borehole.

4.4.4 Backfilling Recommendations

It is recommended that grout be used to backfill around the PVC conduit. Using grout greatly reduces the probability of having voids form between the PVC conduit and the side of the borehole. Sand can be used but it is not recommended since sand can easily get caught and bridge the borehole leaving large voids. It is also possible for sand to migrate out of the borehole due to piping. If sand must for some reason be used, it is highly recommended that care be taken to agitate the sand to break up any bridging. Sand must be added slowly to a water-filled annulus, and it must be agitated starting from the bottom of the borehole using a flexible rod or cable fishing tool.

Note: Use grout instead of sand to backfill around the PVC conduit. Sand is harder to place without voids, and could migrate.

The grout mix recommended for installation of SAA is given in Table 4.3, below. It is important to use bentonite powder for the mix since bentonite pellets will not incorporate well into the grout. The mix below, results in a very soft grout which will minimize the influence of the grout on the soil displacement measurements. This is particularly important when installing SAAs into large diameter boreholes in which the cross-sectional area of the grout will be large.

Table 4.3 Grout Mix

Materials	Ratio by Weight
Portland Cement	1
Water	6.6
Bentonite	0.4 (adjusting as required)

When mixing the grout, start by mixing the cement and water first. Do NOT mix the bentonite and water first, or you will not be able to mix the appropriate amount of cement into the grout, or the grout could flash set.

Once the cement and water are mixed, add in the bentonite. Mix the bentonite in a bit at a time until the grout mix resembles heavy cream. The consistency is very important, too watery a mix will result in shrinkage and segregation, too thick and it will not be possible to pump the grout.

Note: The grout mix given above is a guideline only. It is recommended that you design a grout mix which will have a similar strength and comportment as the soil in which you are installing the SAA.

Some shrinkage and settlement of the grout should be expected. It is recommended that the grout be topped up 24 hours following completion of the initial grouting.

Several types of grouting methods can be used for SAA installations. The most commonly used methods are: tremie grouting, displacement grouting, and staged grouting. Recommendations of which method to use in various situations are given in following sections.

4.4.4.1 Tremie Grouting

Tremie grouting is used in most installations. It is best suited for use in large diameter boreholes. It is also suitable for use when the SAA conduit is being grouted into a large diameter pre-existing conduit. This method can be used for either SAA+PVC installations or to pre-install the SAA conduit prior to receiving the SAA. However, it is important to make sure that the SAA conduit is weighted down prior to grouting to avoid sinuating the conduit.

Note: Tremie grouting will cause the SAA conduit to become buoyant. Make sure that it is properly weighted down using either SAA or chain in order to avoid sinuating the conduit.

In tremie grouting, a tube is inserted to the bottom of the borehole and the grouting is done starting from the bottom of the conduit. Grout is pumped into the tremie tube until it starts to appear at the borehole surface (Figure 4.18). The tremie tube is then removed from the borehole, or it may be left in place ("sacrificed").

When tremie grouting is used, it is important to take into consideration the dimension of the tremie tube. Too big and it will not fit in the borehole or casing with the SAA conduit, too small and it will be impossible to pump grout to the bottom of the borehole.

In order to make the insertion of the tremie tube easier, it is recommended that it be inserted at the same time as the SAA conduit.

Avoid excessive pump pressures when grouting.

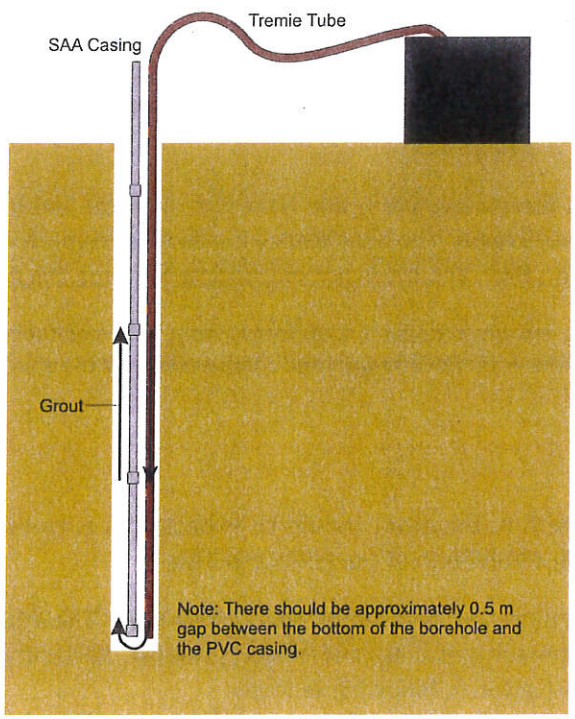


Figure 4.18 Tremie grouting SAA conduit into a borehole.

4.4.4.2 Displacement Grouting

Displacement grouting should be used when the SAA conduit is being inserted into a small borehole and there is not enough room for both the SAA conduit and a tremie tube.

Note: The SAA+PVC installation method must be used when doing displacement grouting. If an empty conduit is placed inside the grout column, the buoyancy effects will make it difficult to fully insert an empty SAA conduit. Timing is also important; the grout should not be placed until the SAA+PVC assembly is ready for insertion.

In displacement grouting the amount of grout required to fill the borehole is estimated using the diameter of the borehole and the diameter of the SAA conduit. The grout volume required is then mixed and placed in the borehole. As the SAA conduit is inserted into the borehole, the grout will be displaced upwards, filling the annular space between the borehole and conduit. Prepare the SAA+PVC assembly prior to placing the grout.

4.4.4.3 Staged Grouting

In some cases, it is not possible to use the SAA to weight down the conduit during the grouting process. For very long SAAs, the buoyancy effects may be too great to easily resist using chain. In these cases, it may be desirable to use staged grouting.

In staged grouting, the SAA conduit is inserted into a borehole along with a tremie tube, and the borehole is grouted in two or three stages. The grout should be allowed to set for 24 to 48 hours prior to doing the next stage.

This method is recommended for SAA conduits over 60 m in length which are to be installed prior to receiving the SAA shipment.

4.5 *Recommended Installation Method for Horizontal Installations*

The recommended installation method for horizontal installations is similar to the method outlined in Section 4.4.1 for SAA+PVC installations in vertical boreholes. In this case, the SAA+PVC is placed in a trench and surrounded by bedding sand as shown in Figure 4.19. The purpose of the bedding sand is to protect the SAA from large particles and stones which are commonly found in construction fill material. The work flow for horizontal installations is shown in Figure 4.20.

Note: For most horizontal installations the cable end of the SAA is used as the reference point, though the far end can also be used as the reference point. The instructions below assume that the reference end is located at the cable end of the SAA.

4.5.1 Preparing the Trench for Horizontal Installation

It is recommended that the SAA be installed into a trench that is at least 300 mm (1') deep by 300 mm (1') wide. The depth of the trench needed depends on the particle distribution of the soils surrounding the trench. The SAA is to be surrounded by bedding sand, as shown in Figure 4.21, to protect it from damage and minimize any local effects from large rocks.

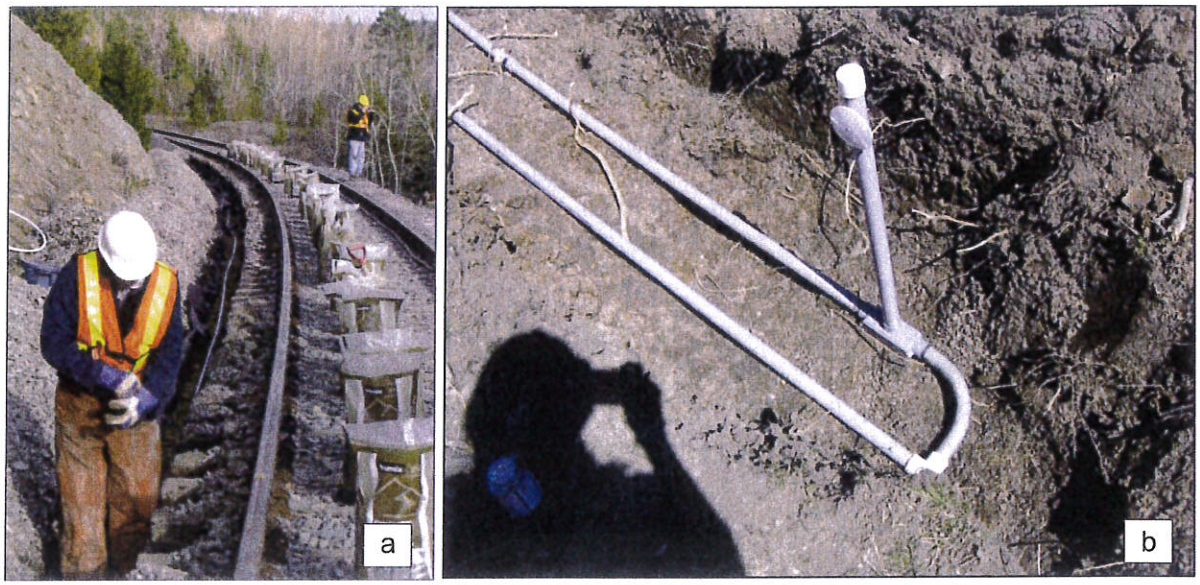


Figure 4.19 Horizontal installation of SAA adjacent to train tracks. (a) SAA+PVC placed in trench containing bedding sand and geotextile to wrap around SAA. (b) Survey marker placed at reference end of SAA. Ensure the marker is associated with a known location along the sensorized portion of the SAA.

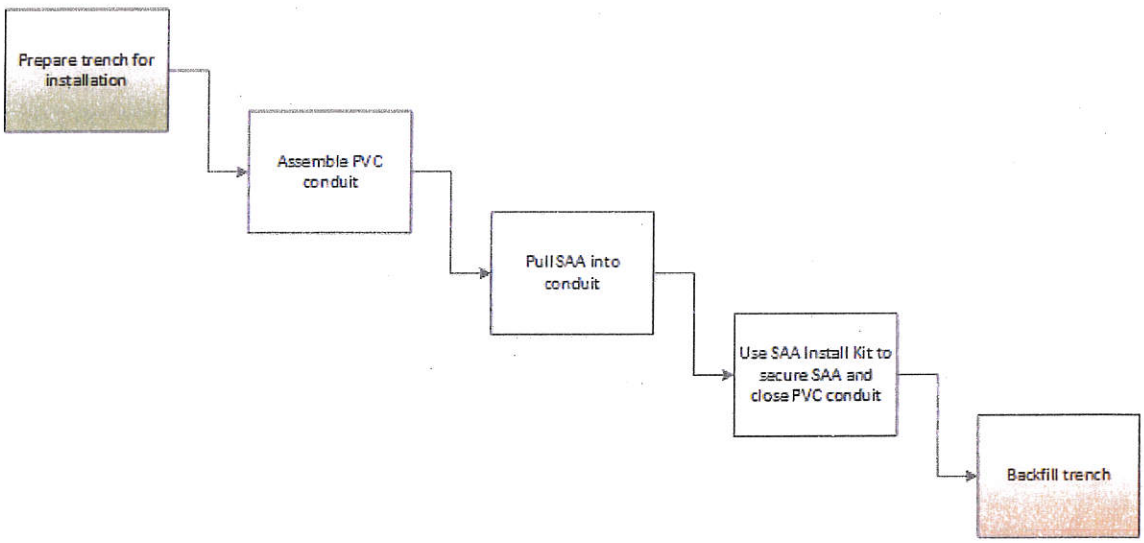


Figure 4.20 Work flow for installing horizontal SAAs

Use of a geotextile is recommended in order to provide separation between the common fill and the bedding sand fill. Make sure that the geotextile is wide enough to line the trench and wrap over top of the sand, completely enclosing it at the end of the process.

After the geotextile has been placed in the trench, place a layer of bedding sand in the trench. The thickness of the bedding sand layer placed below the SAA depends on the gradation of the subgrade soil. It is recommended that the bedding layer be as thick as the largest particle commonly found in the subgrade. The minimum recommended thickness of the bedding sand placed below the SAA is 150 mm (6").

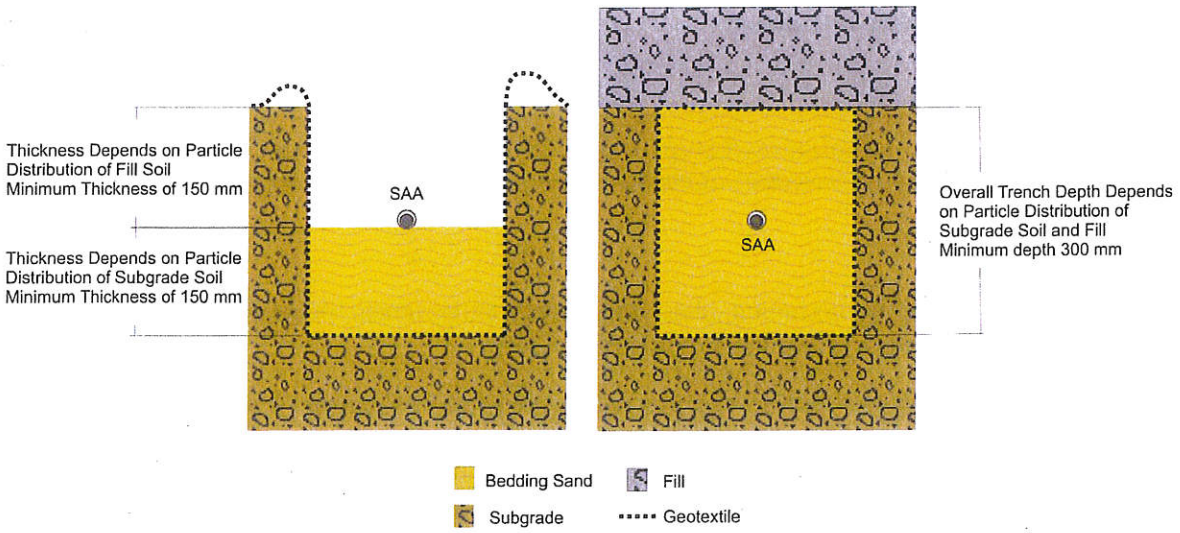


Figure 4.21 Trench for installation of horizontal SAA

At this point the trench is ready for the placement of the SAA conduit. The conduit can be assembled directly in the trench, or it can be assembled next to the trench and then placed inside the trench before pulling the SAA inside.

4.5.2 Assembling SAA Conduit for Horizontal Installation

In horizontal installations, it is sometimes easier to use a larger conduit than the one typically recommended for vertical installations. The larger conduit makes it easier to extract the SAA when the monitoring program is done. It also makes it possible to account for ovalization of the conduit due to the soil load above the SAA. An example of how to calculate pipe ovalization due to live and dead load is presented in Appendix J. Make sure to select the appropriate pipe cross section for your particular site.

When assembling SAA conduit, all PVC conduit ends should be kept clean from dust, oil, and snow. Look inside the PVC conduit to make sure that no foreign objects are inside it. The edges of conduit over which the SAA is being pulled should be smoothed with a deburring tool to prevent abrasion, as shown in Figure 4.5.

Lay out the SAA conduit either adjacent to the trench in which you are installing the SAA or in the trench itself. If you are using rope to pull the SAA into the PVC, **make sure to pull the rope through all conduit sections before gluing these together**. The install kit includes a wire to enable fishing a rope through each section.

When gluing the PVC using PVC primer and cement, make sure to follow the manufacturer's instructions for the product you plan to use.

Note: It is important to follow the PVC Primer and Cement manufacturer's recommendations for set times and temperature ratings. The most common Cements may fail at low temperatures. Choose products which are suitable to the environment and weather you will be encountering.

Glue the bottom part of the top stack included in the SAA Install Kit to the cable end of the conduit at this time.

4.5.3 Pulling the SAA Into the Conduit

Note: It is not necessary to check for twist on horizontal SAA installations. However, if you plan to re-use the SAA for a vertical installation at a later time it is important to avoid applying any twist.

Prior to pulling the SAA into the conduit, place the conduit in the trench. Make sure that the conduit is straight as this is essential to pulling the SAA into the conduit.

Place the SAA reel on the reel stand so that the SAA unreels from the bottom (Figure 4.6a). Once this is done, pull the rope through the eyelet and secure with electrical tape (Figure 4.6b). It is also possible to use a cable fishing tool to pull the SAA. However, if you opt to use one, use a swivel connection between the SAA and the cable fishing tool to allow the SAA to freely rotate during the pulling process. When ready, pull the SAA into the conduit, making sure that there is someone on hand to guide the SAA into the conduit (Figure 4.6c). Keep pulling the SAA until one or two segments are completely out the far end of the conduit (Figure 4.6d).

After the SAA is pulled into the conduit, check the X-marks at the near and far ends to make sure that they are aligned, if the X-mark is located on the underside of the SAA, lift the bottom segment to verify the alignment.

Once you have confirmed that there is no twist in the SAA, push a piece of PVC conduit which has been cut to length over the eyelet end of the SAA and glue it in place. Also glue the end cap in place at this time.

4.5.4 Closing the PVC Conduit Using the SAA Install Kit

Either end of the SAA may be used as the reference end in horizontal installations. The SAA should be secured at one end of the conduit, but never at both. There should be at least one 25 mm (1") or room at the unsecured end. These measures prevent rotation, and allow for some expansion and contraction of both the SAA and PVC.

Unlike the SAAs installed vertically, it is not necessary to compress the joints for horizontal SAAs. Ensure that the reference end of the SAA is stationary, placed in a zone where movement is not expected to occur. Once this is done, tighten down the set screw at the reference end. This will stop the SAA from sliding at this end of the conduit. If you wish to enclose the SAA within the SAA conduit, slip the rest of the top stack over the cable and screw the top stack together. Tighten the gland at the top of the top stack until the rubber gasket seals the cable.

It is possible to place a survey marker at the reference end of the instrument, as shown in Figure 4.19b. If you do opt to use the survey marker, make sure to place it at the joint between the first sensorized segment and the adjacent unsensorized segment. This will ensure that it corresponds to data at the first vertex of the polyline describing the SAA data relative to the reference end. Any additional survey markers should be placed at known join locations along the sensorized length of the SAA.

It is recommended that the cable between the SAA and the logger or measurement point be protected by conduit. The conduit will protect the cable and make it easy to replace in the event of a mechanical

break. It is a good idea to have a rope in the conduit to allow cable to be pulled through. It is also a good idea to have some access points for long runs of cable.

4.5.5 Backfilling the Trench

A layer of bedding sand should be placed above the SAA. It is recommended that the bedding sand layer be as thick as the largest particle commonly found in the fill placed above the SAA. The minimum recommended thickness of the bedding sand is 150 mm (6") placed above the SAA. Once the bedding sand is in place, the geotextile can be wrapped over top of the bedding sand. Edges of the geotextile should overlap at least 150 mm (6").

Following this step, it is possible to place fill over top of the SAA and bedding sand (Figure 4.21).

4.6 Retrieving SAAs for Re-Use

Once a monitoring program has been completed, it may be possible to retrieve an SAA and re-use it at another location. SAAs can be removed by hand from a conduit which has undergone deformation in which the minimum bend radius of the conduit is no less than 3.5 m.

When retrieving the SAA, it is important to follow the guidelines discussed in Section 4.2 and Appendix A. In particular it is important to make sure to place the SAA on its reel. Do NOT remove the SAA from its conduit and place it on the ground prior to reeling it up. The safest place for the SAA is either the borehole, or its reel. During the manipulation of the SAA, make sure not to exceed bends of 45° at the joints. It is ok for the joints to have bends >45° when they are on the reel.

Note: Before placing the SAA on the reel, make sure to check the condition of the reel. The air bubbles on the rungs should be generally intact. If not the SAA could be loose on the reel. If the reel is in need of any repairs, carry them out before retrieving the SAA.

The SAA should be placed on a reel the same way each time, matching the factory-reeled condition. Start by rolling the cable and securing it to the reel using zip ties. Then position the PEX as shown in Figure 4.22a. Note that there is a hole in the side of the reel which is used to secure the SAA onto the reel. The hole should line up between the two PEX rings located at the top of the SAA. When placing the SAA on the reel, make sure that the X-mark on the PEX faces straight away from the reel. This will help make sure that the on-reel dots are facing outward. If the on-reel dots are not facing out, then something is wrong. See Figure 4.22b for the appearance of the on-reel dots.

Reeling the SAA will take several minutes, since it is necessary to make sure that the joints are not twisted during the process. Make sure that the segments are all lined up neatly as they are placed on the reel, and that the joints are all lined up. Once you have finished placing the SAA on the reel, make sure to secure the SAA to the reel.

Note: Make sure you place the SAA on the reel in the same position you took it off. The X-mark on the PEX should be pointed straight out from the reel. The joints should all be neatly arranged and lined up on the reel.

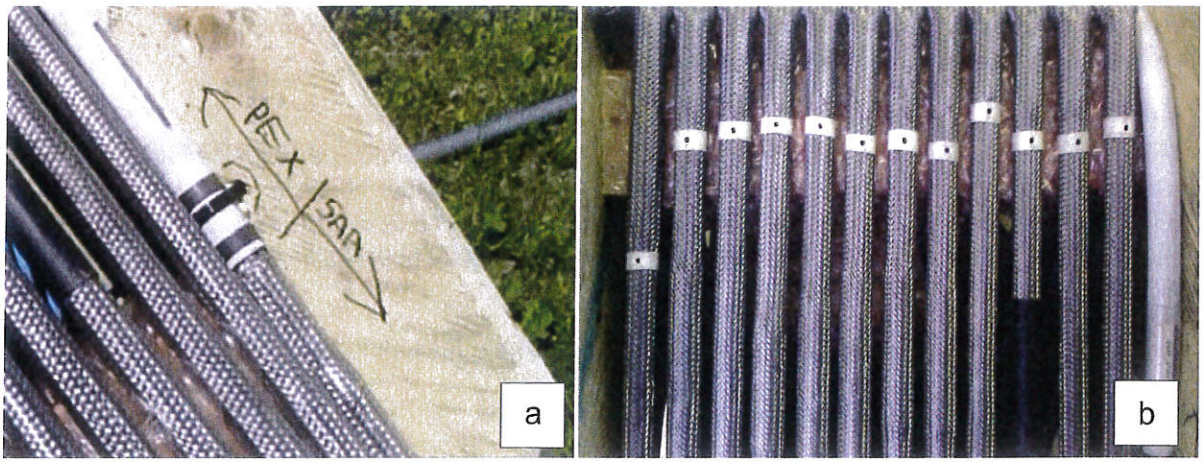


Figure 4.22 Reel positions for SAA. (a) Note location of PEX/SAA interface. (b) Make sure all the On-reel dots are in the same position.

At this point you should make sure that the On-reel dots are all pointed in the same direction. If the SAA was reeled properly, these should all be pointing straight up out of the reel, as shown in Figure 4.22b. If the On-reel dots are all oriented in the same direction as shown, then it is possible to either store the SAA or move it to another site for re-use.

If the on-reel dots are not oriented in the same direction, it is likely evidence of twist in the SAA. Contact Measurand for assistance if this happens.

5. Collecting SAA Data Using SAA Recorder

SAARecorder can be used to record SAA data manually. This is usually done in cases where readings are taken on an interim basis. It is often helpful during installation to record some data using SAARecorder in order to help with any subsequent troubleshooting. This chapter contains basic instructions on setting up the SAA, recording data, and exporting data in SAARecorder. For more instructions on how to use SAARecorder, please refer to the SAARecorder Software Manual found in SAASuite.

5.1 *Getting Started in SAARecorder*

To collect data using SAA Recorder you will need to connect the SAA to your computer via an interface as discussed in Chapter 3. Once SAARecorder is able to find and communicate with the SAA, the program view shown in Figure 5.1 will open on your computer screen.

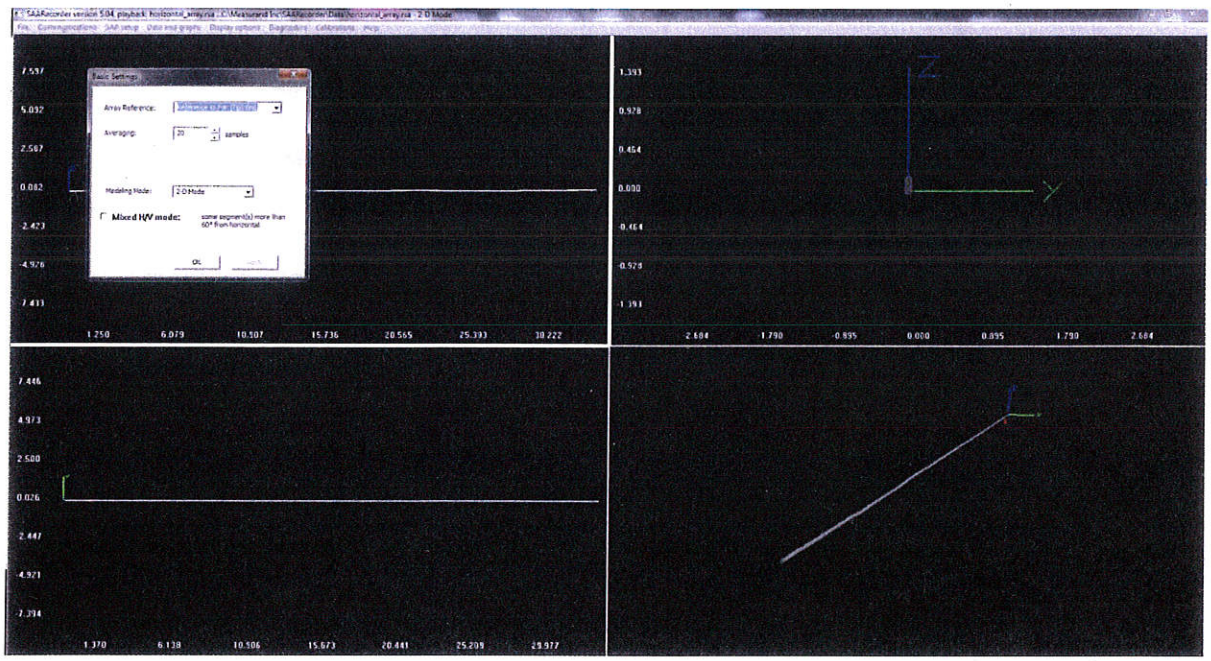


Figure 5.1. Program view from SAARecorder showing a single SAA. This view shows three orthographic views of the SAA, plus a fourth perspective view (lower-right corner).

In the upper left corner, you will find the Basic Settings window (Figure 5.2). The Basic Settings window allows the user to view and change the "Array Reference", the amount of averaging to perform, whether or not to use the "Averaging-in-Array" (AIA) mode, and the modeling mode (2-D, 3D or Mixed H/V). These settings must be set correctly in order to view the SAA properly in SAARecorder.

The "Array Reference" setting allows the user to select which end of the SAA (near (cable) end or far (tip) end) to use as the reference end or starting point for SAA calculations.

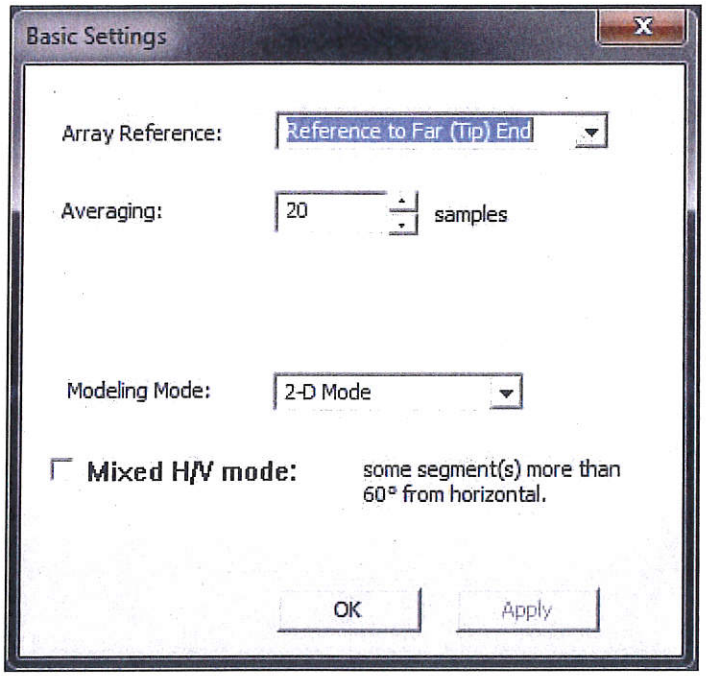


Figure 5.2. Basic Settings Window. It allows the user to view and change the reference point for the SAA (near or far), the amount of averaging to perform, and the modeling mode (2-D or 3-D).

The "Averaging" setting allows the user to specify how many samples of raw data are averaged on an ongoing basis. The averaging value can be set to anywhere from 1 (i.e. no averaging) to 1000 (i.e. average the last 1000 samples for computing displayed data). Setting the averaging value in SAARecorder does not affect the contents of a raw data file, although it does affect data exports to either SAAView or one of the other text output formats. In most cases it is preferable to use AIA Mode, as described in Section 2.2.2. To use AIA mode, make sure the AIA mode check box is checked. Normally, it is recommended that the averaging level for AIA data collection be set to 1000. Although sometimes, when collecting data in noisy environments where there is some significant vibration, it is preferable to use a higher averaging level. An AIA averaging level of up to 25500 can be used.

Calculations for the SAA(s) can be made in one of three possible modes: (i) Near Vertical (3D), (ii) Near Horizontal (2D), and (iii) Mixed H/V mode (Convergence). The near vertical mode is used if all segments of the SAA are greater than 30 degrees relative to the horizontal. The near horizontal (2D) mode is appropriate when no sections of the SAA are inclined more than 60 degrees relative to the horizontal. The mixed (convergence) mode is appropriate when one or more, but not all, segments of the SAA are inclined *more* than 60 degrees relative to the horizontal. This mode is normally used for SAAs that are being used to monitor circular shapes, such as the circumference of a tunnel. For more information on using the mixed mode, please refer to the SAARecorder Software Manual.

5.2 *Recording SAA Data*

To record SAA data to a "raw shape array" (.rsa) file on your PC, select the 'File | Save Raw Data File' menu option in SAARecorder, or press the Spacebar key. This brings up the recording window shown in Figure 5.3.

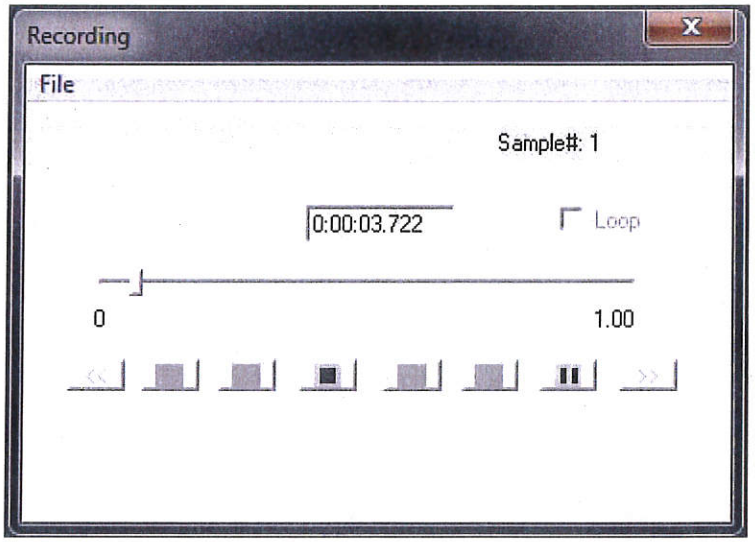


Figure 5.3. Playback / Recording window for recording raw shape array (.rsa) data. The recording can be stopped by closing the Playback / Recording window, pressing the "stop" button in the above window, or selecting 'File | Close Raw Data File' from the main menu. Once the recording has been stopped, a dialog appears prompting you to select a filename for the recorded data.

Selecting the 'File | Save Raw Data File' menu item saves the raw data as soon as it arrives at the PC.

Note: Before starting a long-term recording session, check your Windows Power Management settings to make sure that the computer will not automatically power down the hard drive or go into a reduced power state if left unattended for an extended period of time.

5.3 *Exporting SAA Data*

Raw data recorded in SAARecorder as .RSA files can be converted to a multi_saa_allcart.mat file that can be easily opened in Measurand's SAAView software. SAAView has many graphical interfaces and options available for viewing SAA data over a long period of time. In order to convert one or more .RSA files to a multi_saa_allcart.mat file which can be opened in SAAView, select the 'File | Export raw data to SAAView' menu item of SAARecorder.

Note: The Array Reference and the Modeling Mode settings need to be set to the appropriate settings when exporting to SAAView.

You will next be prompted to select the raw data file you wish to export. Once a file has been selected, you will be prompted to select the averaging options for the conversion (Figure 5.4). After the averaging options have been set, you will be prompted to select the SAA conversion parameters (Figure 5.5). For this example, the SAA is horizontal and the reference end is at the cable end or "Near End" of the SAA. As such the "Vertical" and "Ref=Far" boxes are left unchecked. For more information on the options shown in Figure 5.5, please refer to the SAACR_raw2data Manual found in SAASuite. Once the

conversion is complete, a pop-up box will open and show you the location where the multi_saa_allcart.mat file is saved. You can now view the file using SAAView (see Chapter 7).

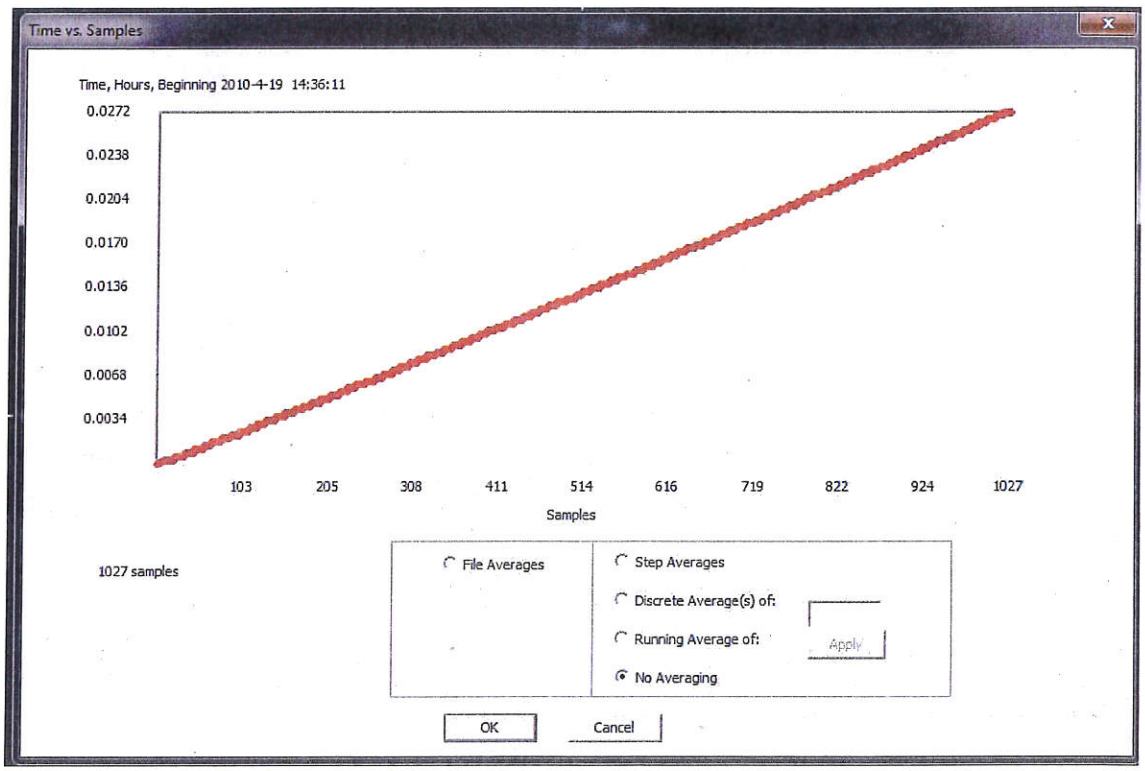


Figure 5.4. Selecting file averaging options.

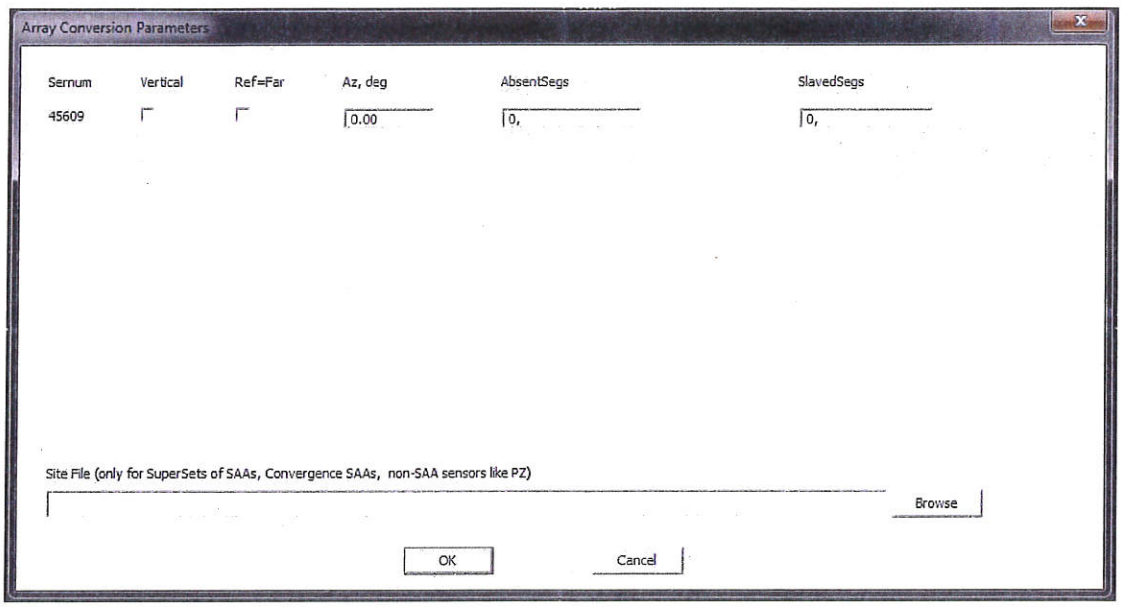


Figure 5.5. Selecting SAA conversion parameters.

6. Collecting SAA Data Using a Campbell Scientific Data Logger

SAA can be configured for use with a CR800, CR1000, or CR3000. For simplicity's sake, this chapter will only discuss the CR1000. Unless otherwise stated, it can be assumed that everything stated for CR1000 loggers in this chapter applies for CR800 or CR3000 loggers.

In order to connect the SAA to the CR1000, you will need to use Measurand's SAA232 (or SAA232-5) interface device and utilities included in the SAASuite software. The SAA232 interface is necessary to properly cycle power through the SAA and to convert the SAA's RS485 communication protocol to the RS232 format recognized by the CR1000. The following utilities included in SAASuite are used to configure the logger or convert data collected from the logger into Cartesian data:

1) SAACR File Generator: a utility used to create the program files that will allow the user to collect data from the SAAs sensors;
2) Conversion Config: a utility used to create the conversion preferences file used for automatic data collection; and
3) SAACR_raw2data: a conversion utility that converts the raw data to Cartesian format viewable in SAAView.

In cases where a large number of third party vibrating wire sensors will be monitored, a CR1000 or CR3000 is advantageous over a CR800.

6.1 *Hardware Setup*

The CR1000 allows up to 20 SAAs to be connected to a single logger (the CR800 allows for up to 10 SAAs connected via two SAA232-5s). Each COM port on the CR1000 requires a Measurand SAA232 or SAA232-5 device (Figure 6.1) to connect an SAA. A wiring guide for connecting the SAA232 to the CR1000 and to the SAA is located on the side of the SAA232 or SAA232-5, as can be seen in Figure 6.1. Wiring diagrams for back panels containing CR1000, an SAAREG, and SAA232 or SAA232-5 are shown in Figure 6.2 and Figure 6.3, respectively.

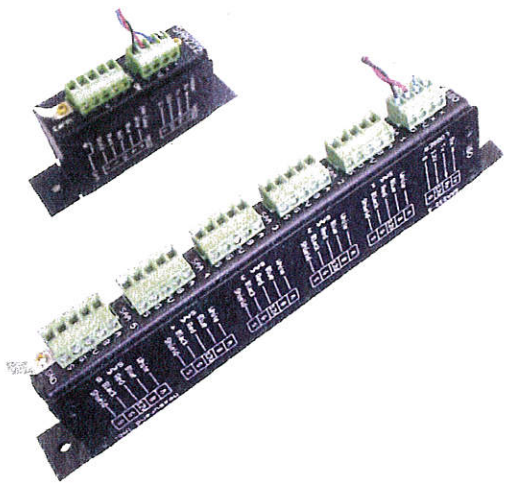
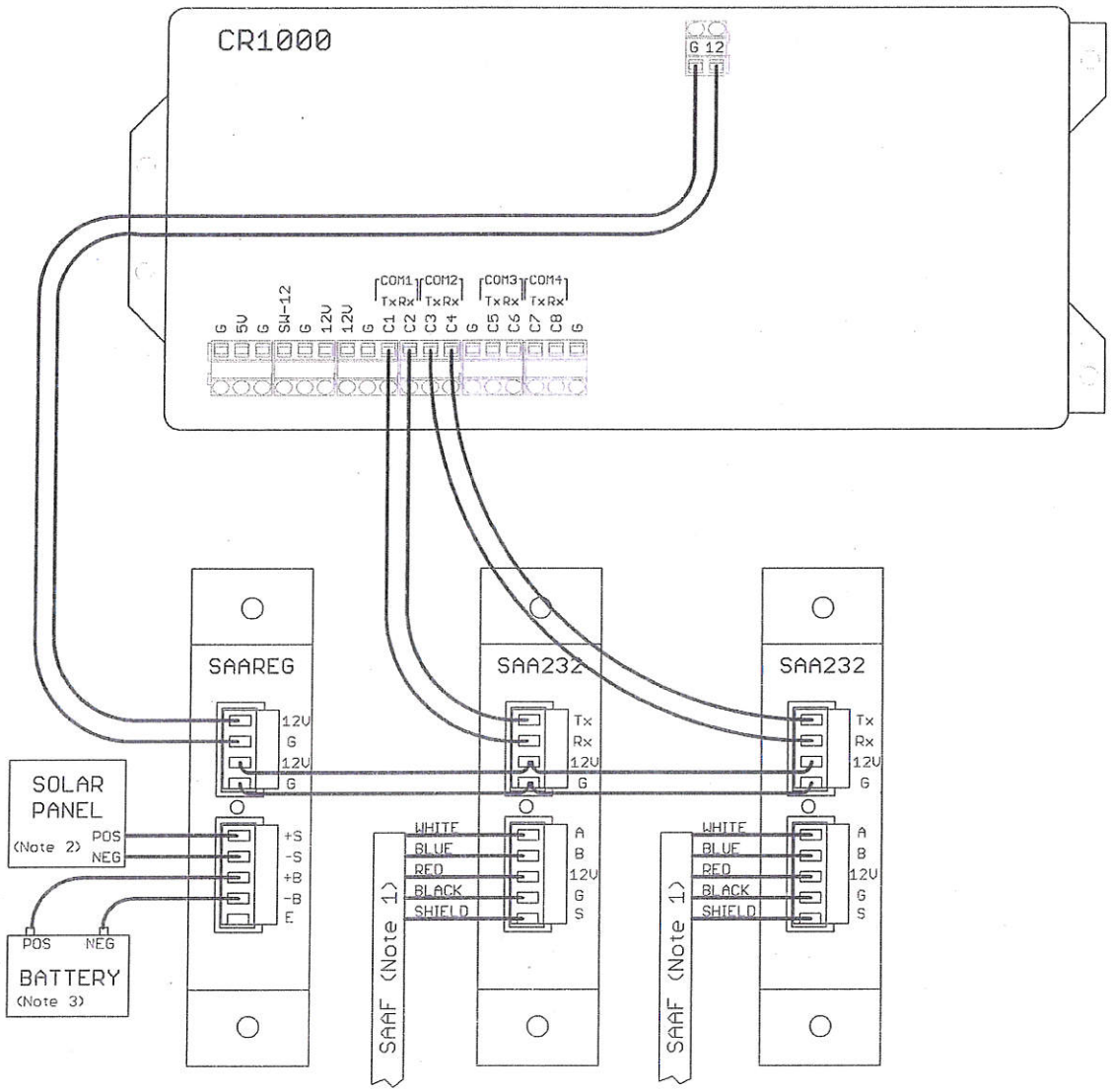


Figure 6.1: SAA232 and SAA232-5 for connecting SAA to COM ports on CR1000 loggers. Note the SAA wiring guide on the side panel.



Note 1: Ensure that SAAF serial numbers and COM port numbers are matched, as specified in the Main Program of the CR1000. Do not arbitrarily move SAAFs to other serial port COM numbers.

Note 2: Solar Panel can be replaced with a mains charger if available

Note 3: Sealed lead acid deep cycle 12V battery

Figure 6.2: Wiring diagram for CR1000 with SAA232.

An example setup using a CR800, 2 SAA232s, and an Airlink Raven XT modem is illustrated in Figure 6.4. If the back panel assembly and wiring has been done by Measurand, you will only need to connect the SAA wires to the SAA232 or one of the SAA232-5 channels. This should be done prior to connecting the power to the logger (i.e. the 4-pin green connector on SAAREG should not be plugged in while you are wiring the SAAs into the SAA232 or SAA232-5). The green connectors can be removed from the SAA232 for easier wiring. When wiring the SAAs to the SAA232 and logger, make sure to note which SAA (serial number) is connected to which SAA232 or SAA232-5 channel (if applicable), and the COM port to which the SAA232 or SAA232-5 is connected. These must match the logger program.

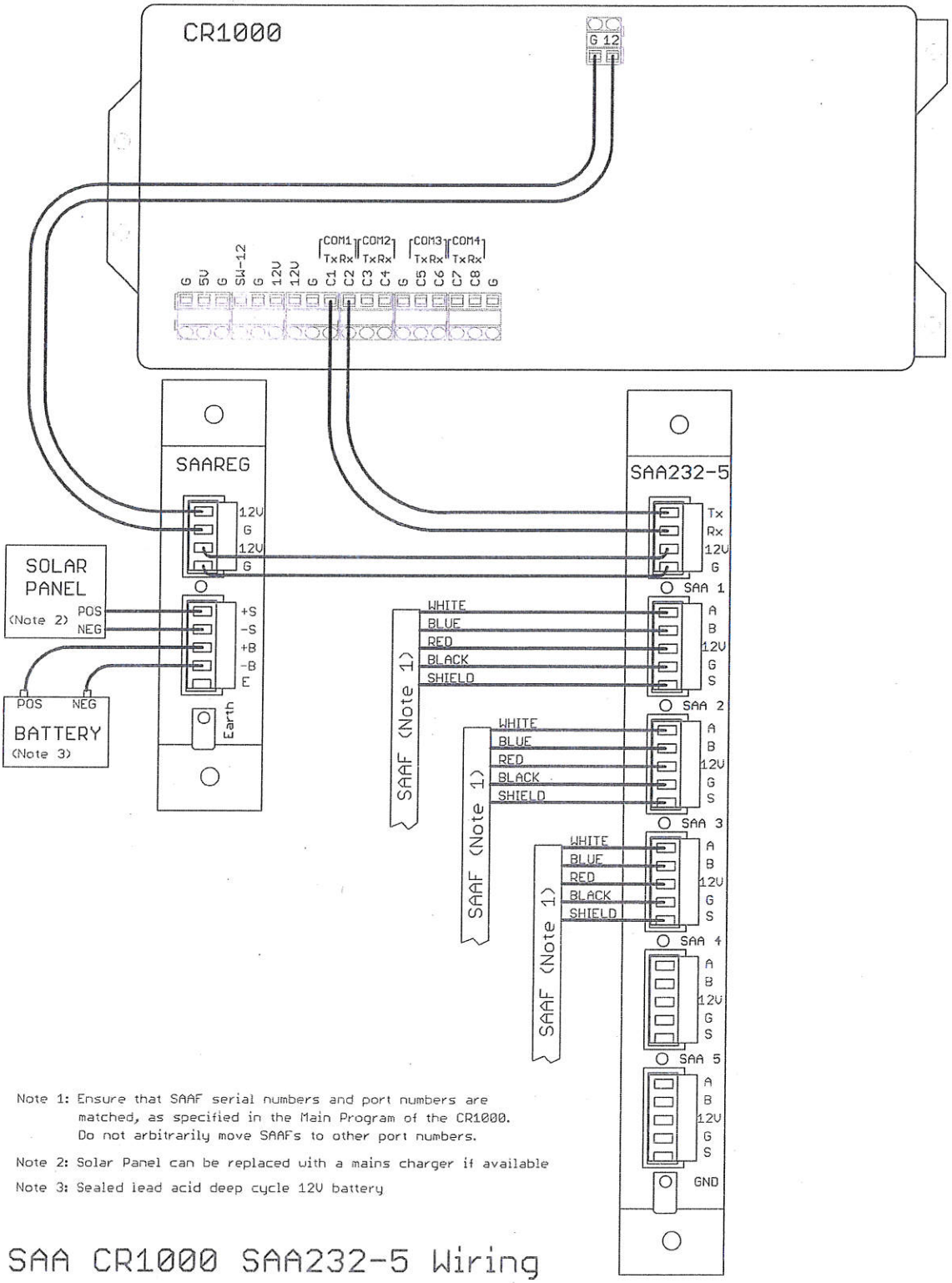


Figure 6.3: Wiring diagram for CR1000 with SAA232-5.

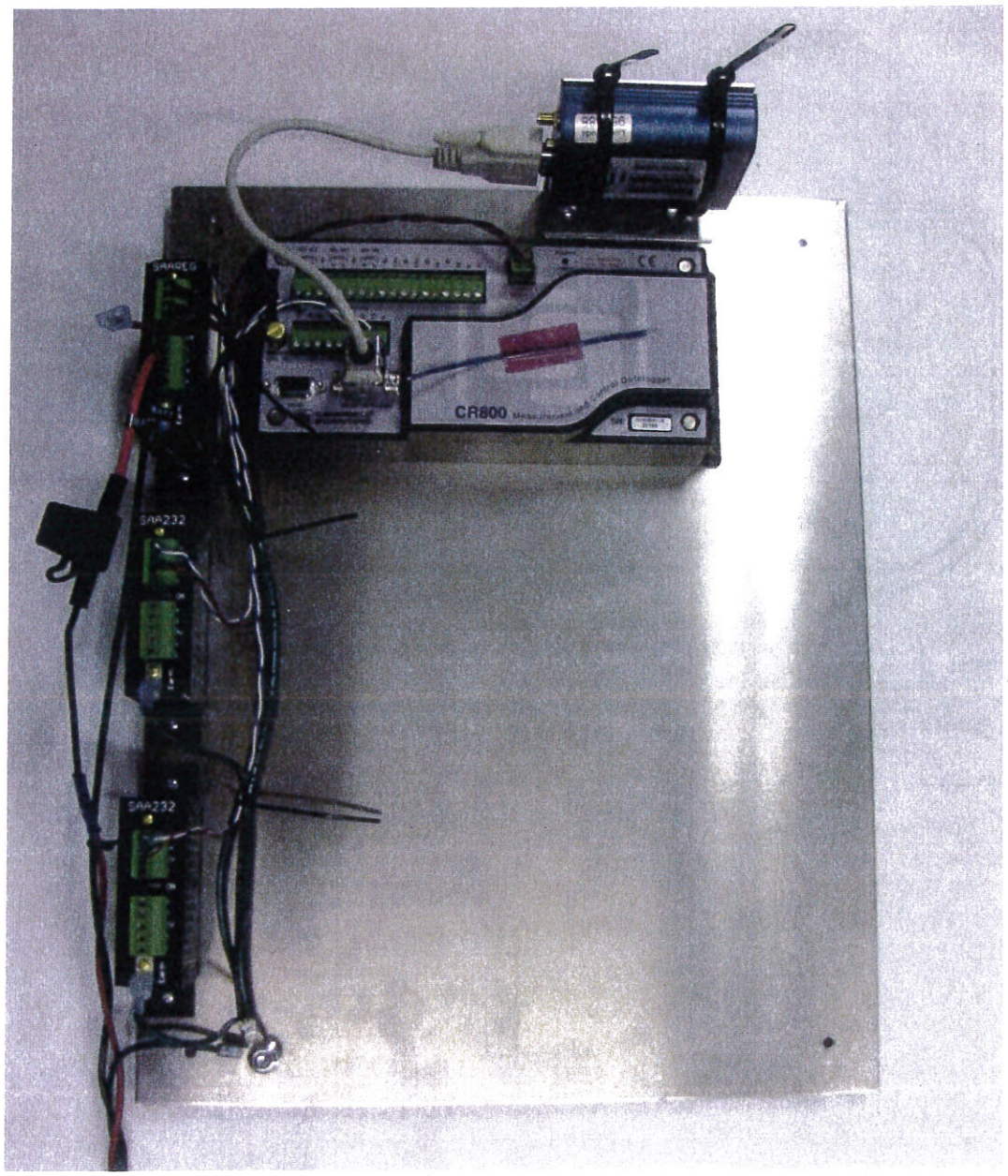


Figure 6.4: Example CR800 & SAA integration using one SAAREG, two SAA232, a CR800 logger, and a Raven XT Wireless Modem.

When setting up the earth station, it is a good idea to connect the power after the SAAs are connected to the logger. In order to safely connect the power to the earth station follow the steps outlined below:

1) Make sure fuse from Battery is connected.
2) Connect battery to regulator.
3) Connect the solar panel to the regulator.

Once these steps are completed, make sure that there is a logger program loaded. If there is none, load one and test the SAA and cell modem for functionality. Information on how to create a logger program and load it is provided in the following sections of this chapter.

6.2 Setting Up the CR1000 Logger

Note: The CR1000 logger setup can be done prior to taking the earth station in the field for installation, saving time in the field.

6.2.1 Using LoggerNet

Setup of the CR1000 to collect SAA data requires a basic understanding of Campbell Scientific's LoggerNet software. For more information on Campbell Scientifics's LoggerNet software, visit the Campbell Scientific website to obtain the user manual (http://www.campbellsci.ca/). The LoggerNet toolbar is shown in Figure 6.5. For the purpose of this manual, the following utilities will be used:

1) Setup: Utility used for connecting to or changing connection settings of a Campbell Scientific device (e.g, the CR1000, CR3000, or CR800). This utility is found in the Main Menu.
2) Connect: Utility used for managing device connection and manual data collection. This utility is found in the Main Menu.
3) CRBasic Editor: Editor and compiler used for Campbell Scientific programs. This utility is found in the Program Menu.
4) Task Master: Utility used for automating data collection and conversion. This utility is found in the Main Menu.

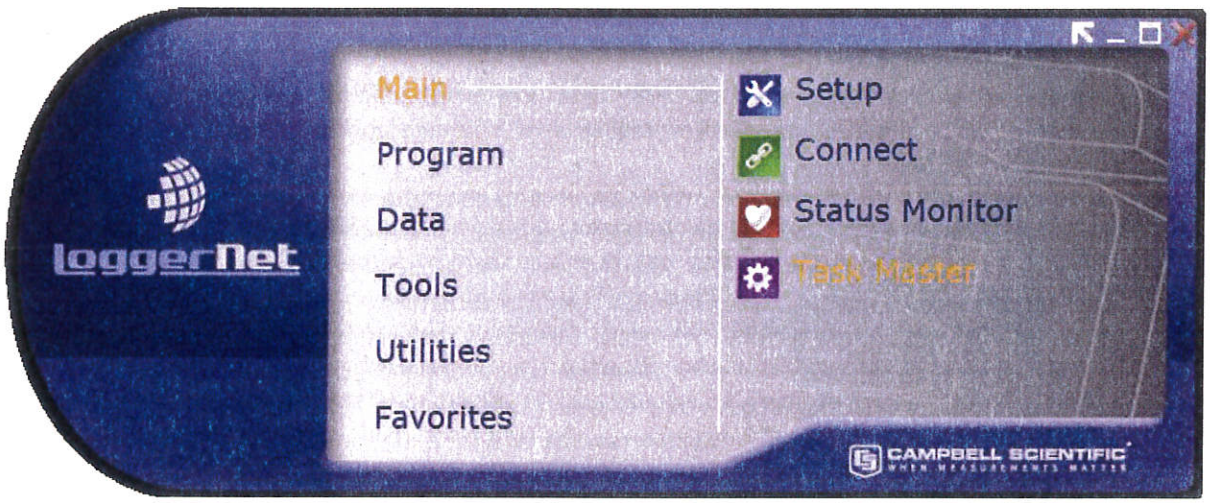


Figure 6.5: LoggerNet Utilities menu.

6.2.2 Creating a Main Program File

Program files for collecting SAA data using the CR1000 can be created using the Measurand SAACR File Generator utility found in SAA Suite (Figure 6.6).

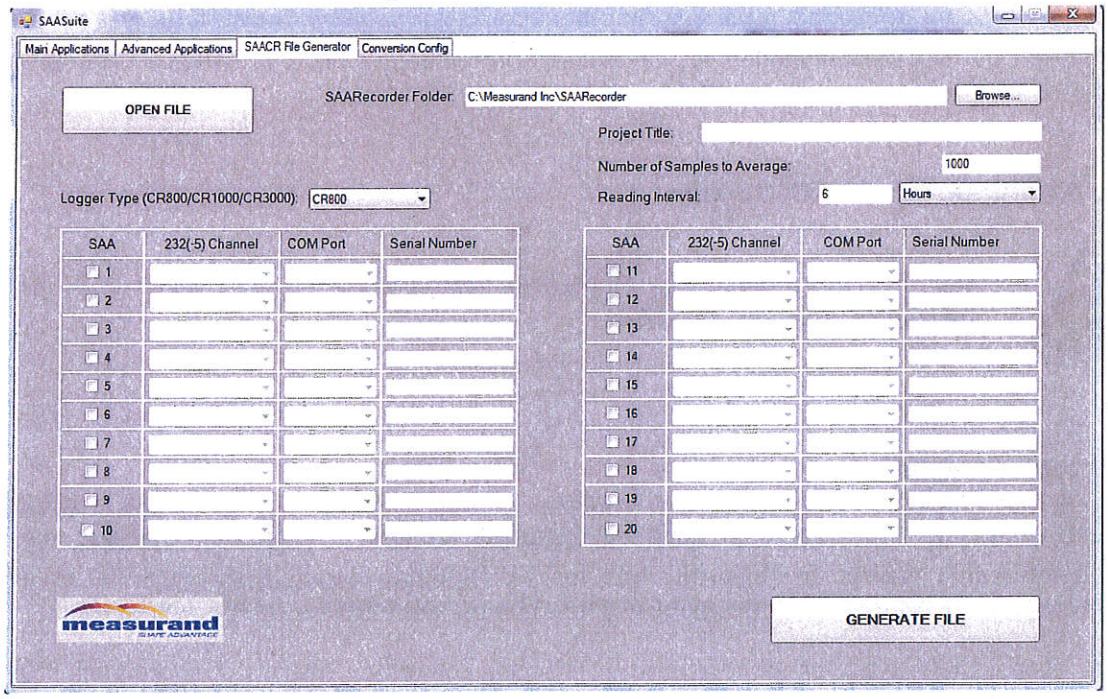


Figure 6.6: SAACR File Generator utility.

The SAACR File Generator utility can be used to create programs for SAAs and SAAPZs (Measurand vibrating wire piezometers). When setting up the program, the following fields must be completed before you generate the program file:

1) Project Title: A descriptor of the monitoring setup;
2) Number of Samples to Average: The number of SAA samples used to compute an average reading. Values can range from 100 to 25500. The larger the number of samples the better the precision, but computational time also increases, albeit, very minimally. With AIA technology, data samples can be collected much faster than previously available. For example, taking the average of 1000 readings (standard averaging level) will take approximately 10 s to output a value from the SAA;
3) Reading Interval: The frequency at which SAA observations are made within the program (also known as 'scan interval'). An SAA can perform measurements at 400Hz (see above), thus taking an average of 1000 samples (typical value) in less than 10 seconds. However, sufficient time must be included to account for other commands and functions within the CR1000, some of which do not occur immediately with each collection. The number of SAAs connected to a CR1000 also affects the collection time. Based on past experience, the logger can work properly for an extended period of time, but will eventually malfunction if the reading interval is less than 10 minutes. For this reason, the minimum reading interval is 10 minutes. For greatest certainty, it is a good idea to increase this by 50%, to allow for circumstances and configurations which we have not yet seen.
4) SAA Table: For each SAA, the following information must be included, (as seen in Figure 6.6):
    a. SAA232 or SAA232-5 Channel that the SAA is connected to (See Figure 6.7);
    b. COM port to which the SAA is connected on the CR1000; and
    c. Serial Number (physically marked on the 'cable-end' of the SAA)

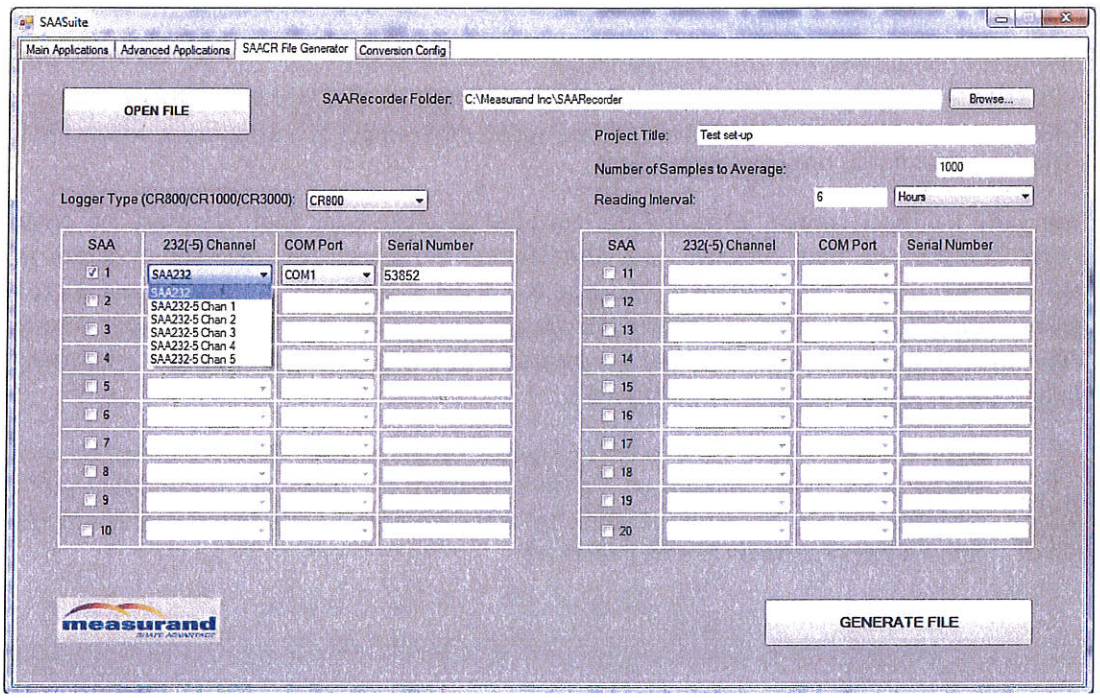


Figure 6.7: SAA232 or SAA232-5 Channel selection.

5) Generate CR1/CR3/CR8 File: The main difference between the CR800, CR1000 and CR3000 is the number of COM ports available, and thus the number of SAAs that can be connected to each. To choose the appropriate data logger type, click the "Generate File" button, and select the desired file type in the save screen (Figure 6.8). Enter the desired file name for the main program file and click "Save". A separate SAA_Include file (see Figure 6.8 for example) will be generated at the same time as the main program file. Both of these files must be loaded onto the logger for the main program file to work properly.

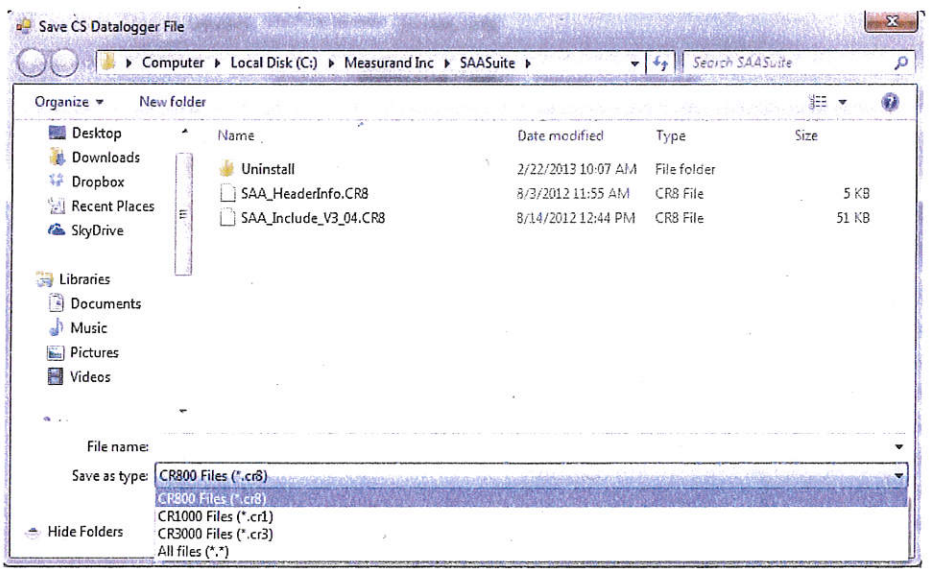


Figure 6.8: Saving a logger program created using the SAACR File Generator utility.

6.2.3 Compiling SAA Program Files

Once the main program and the SAA_Include file have been successfully generated, the main program file can be viewed using the LoggerNet 'CRBasic Editor'. At this time, it is also possible to add other code for instruments or powering the SW12V port on the logger. An example of a program in which additional sensors have been added is provided Appendix K.

Once the code has been added, it should be compiled to make sure that there are no errors. To successfully compile the new program, the SAA_Include file generated with the program is also required. The SAA_Include file should be placed in the same directory as the main program to avoid compilation errors. Note that the SAA_Include file will not successfully compile alone, it gets compiled as part of the main program. Once the two files are located within the same directory, it is possible to save and compile the program as illustrated in Figure 6.9.

Note: The SAA_Include file is not meant to compile on its own. The SAA_Include file should be placed in the same directory as the main program file. When the main logger program is compiled, the SAA_Include file is referenced and is compiled as well. Compile errors will appear if you attempt to compile the SAA_Include file.

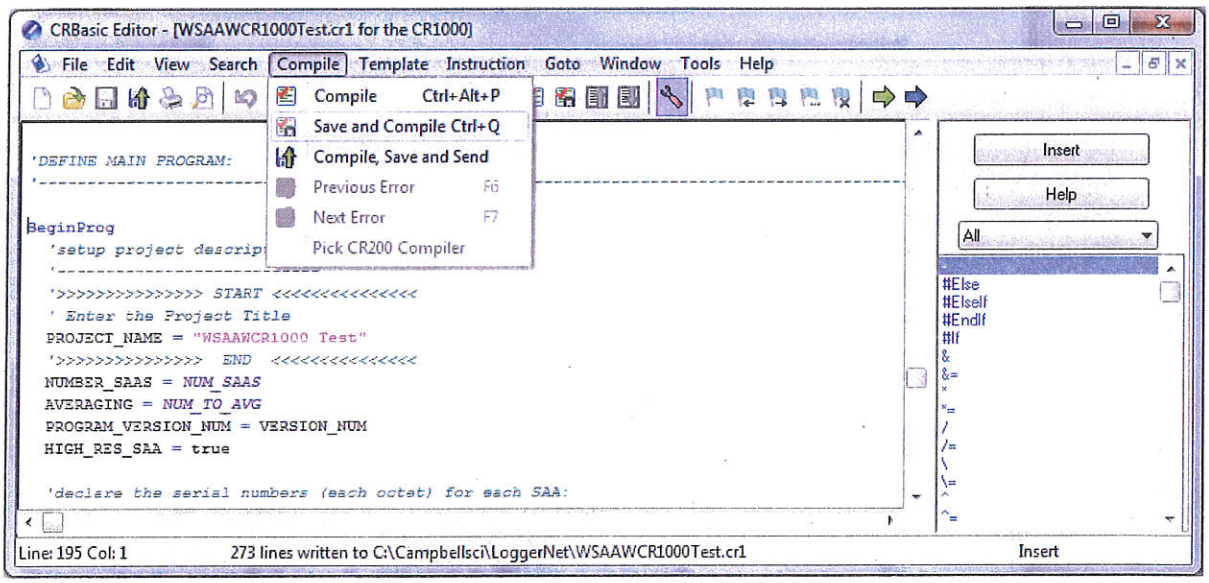


Figure 6.9: Saving and Compiling the SAA logger program.

Note: When using other sensors with the CR1000, it is advised to add the necessary code to the CR1000 program generated for the SAA rather than trying to integrate the SAA specific program with the other sensors. Appendix K provides examples for integrating other sensors into the program.

6.2.4 Uploading Program Files to the CR1000

Once the program has successfully compiled, both the program file and the SAA_Include file must be uploaded to the CR1000 before the main program is run. This is accomplished in LoggerNet using the

'Connect' utility (Figure 6.10). Right click on the Station of interest and click on 'File Control' (the station must be setup using the LoggerNet 'Setup' utility).

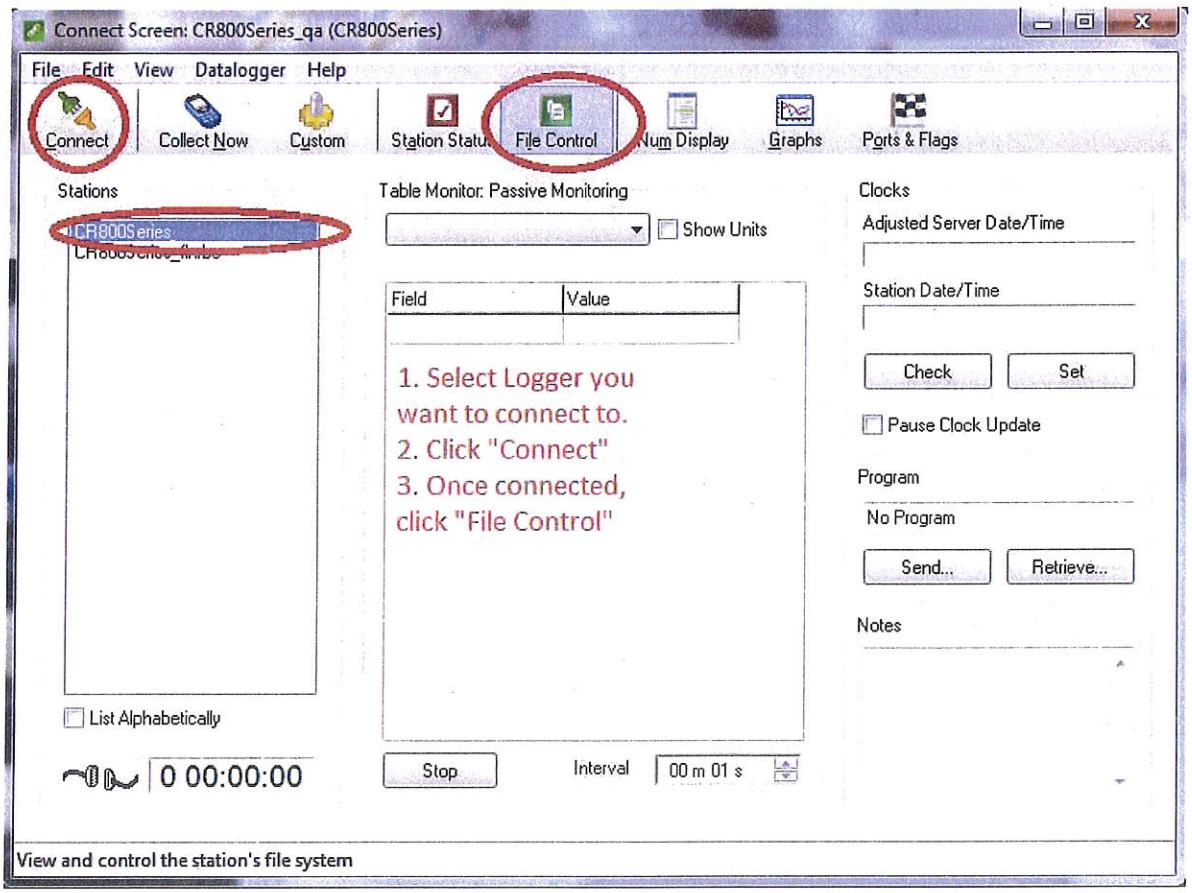


Figure 6.10 Selecting File Control in the LoggerNet Connect utility.

Once the File Control window opens, the 'Send' option is used to place the SAA_Include file on the CR1000, as illustrated in Figure 6.11. The 'Run Now' and 'Run On Power-up' options should be deselected when prompted (Figure 6.12) (since the SAA_Include file will not run as a standalone application).

Note: The SAA_Include file must be placed on the CR1000 before the main program will run. This is accomplished using 'File Control' from the Connect utility.

The main program file can be placed in the same way by using the 'File Control' and 'Send' options. When uploading the main program file, the 'Run Now' and 'Run On Power-up' options should be selected. Note since the run program options are selected, the main program will compile at this point (Figure 6.13). Alternatively the 'Save, Compile and Send' option in the CRBasic Editor can be used. When prompted for Run Options, 'Run Now' and 'Run On Power-up' should be selected.

Note: If you run the program to test the logger set-up, make sure to remove garbage data from the logger by clicking the 'Stop Program' button. When prompted, choose the 'Clear the Program' option. When finished setting up on the site, click 'Run Options' and select 'Run Now' and 'Run on Power-up' to start collecting data. To make sure no garbage data is left behind, when prompted select 'Delete associated data tables created by'.

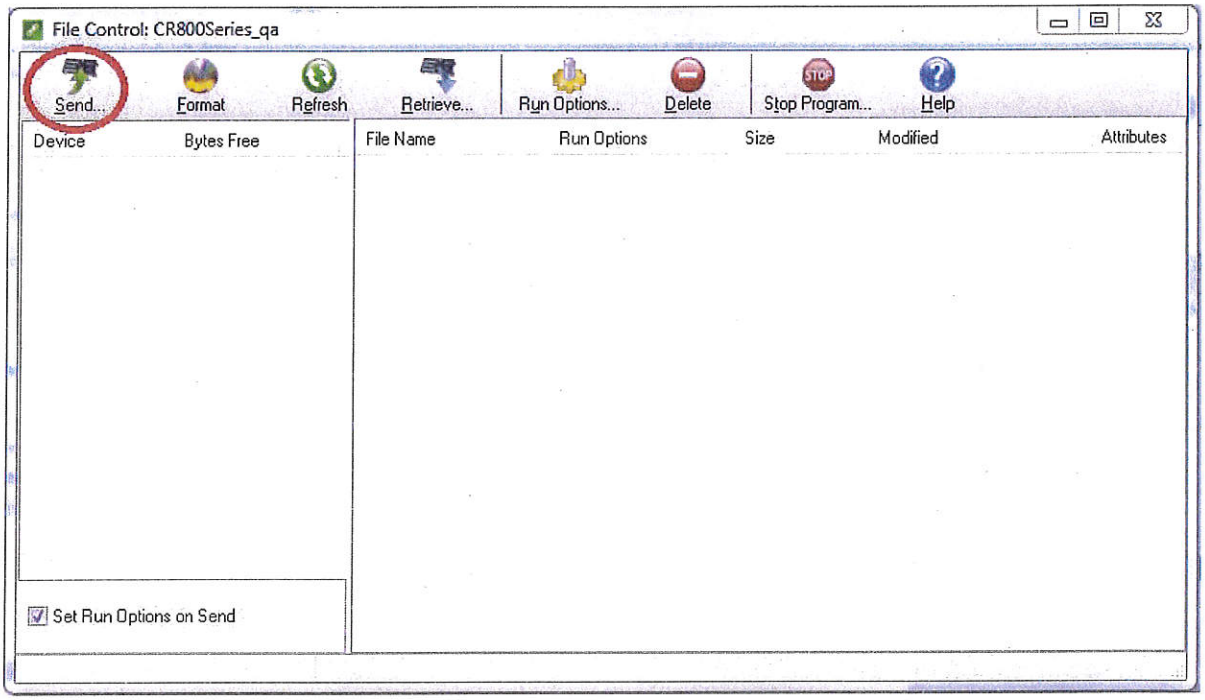


Figure 6.11: Selecting 'Send' option in 'File Control'.

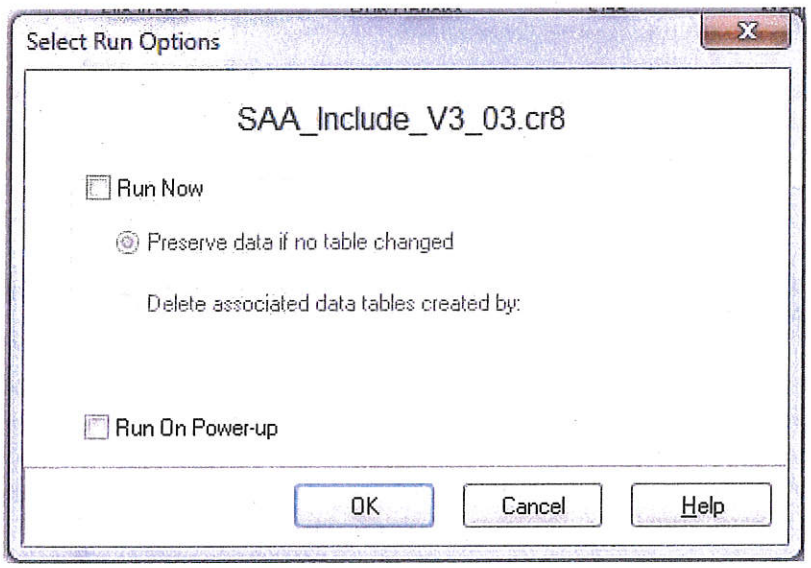


Figure 6.12: Selecting 'Run Options' when sending files to CR1000 logger.

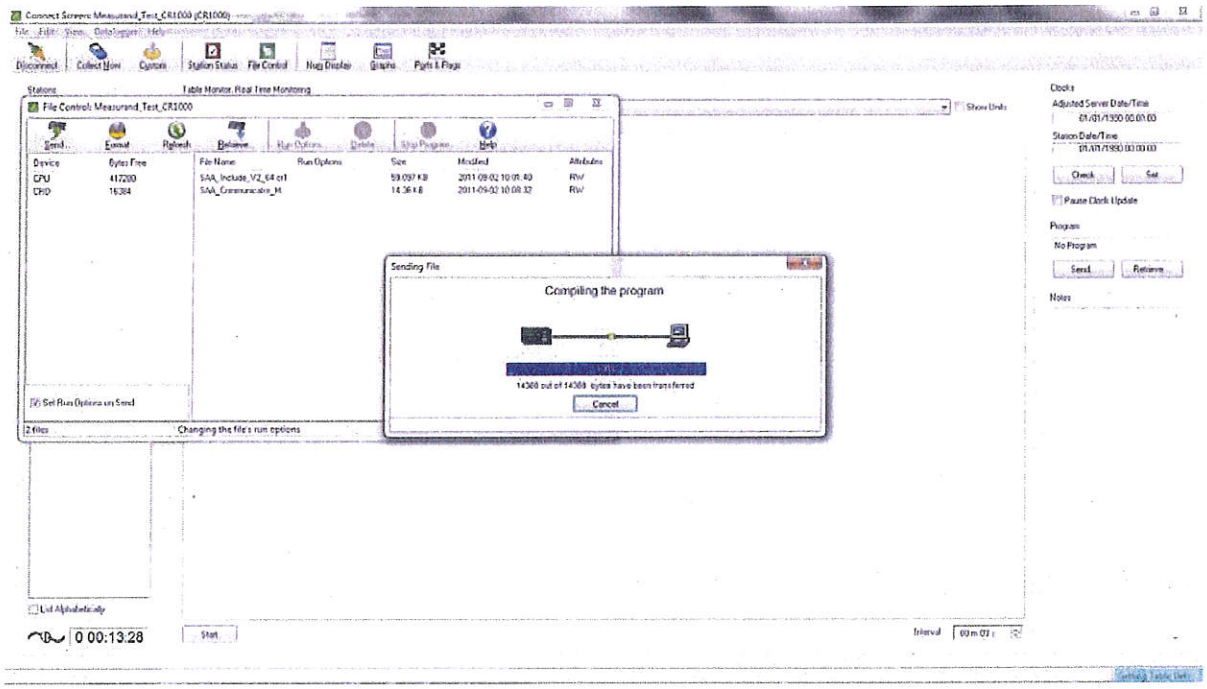


Figure 6.13: Sending a program to the CR1000.

6.2.5 Data File Management

It is critical that the data files generated by the CR1000 are effectively managed. The output folders for CR1000 data files are specified under the 'Data Files' tab in the LoggerNet 'Setup' utility (Figure 6.14). By default, the data is stored in the C:\CampbellSci\LoggerNet directory and given a name of "DataloggerName_TableName_#.dat". It is suggested that the output folder location be changed from this default location to another folder prior to collecting data. It is generally easiest to create a data folder in the C:\Measurand Inc\SAA3D\logger_files\ directory to facilitate automated data conversions later on. An 'archive_raw' folder should be created in the data folder for conversion purposes. To change the output file name you will need to select each file in the 'Tables' box shown in Figure 6.14 and point it towards the desired output folder individually using the 'Output File Name'. It is important not to change the table name, but only the folder. For example the Project Information file is saved by default to C:\Campbellsci\LoggerNet\CR1000_PROJECT_INFO.DAT. This can be changed to C:\Measurand Inc\SAA3D\logger_files\Test\ CR1000_PROJECT_INFO.DAT.

Note: If you opt to change the output file name, DO NOT change the output table name, only change the folder location.

The 'File Output' option should be set to "Append to End of File" (Figure 6.14). The CR1000 keeps track of the last record that was successfully sent to the destination folder. If the output file already exists, the new data will be appended to the end of the file. If the file does not exist or has been moved elsewhere, a new file will be created with all records that have not yet been recorded.

The 'Output Format' should be left at the default ASCII Table Data, Long Header (TOA5).

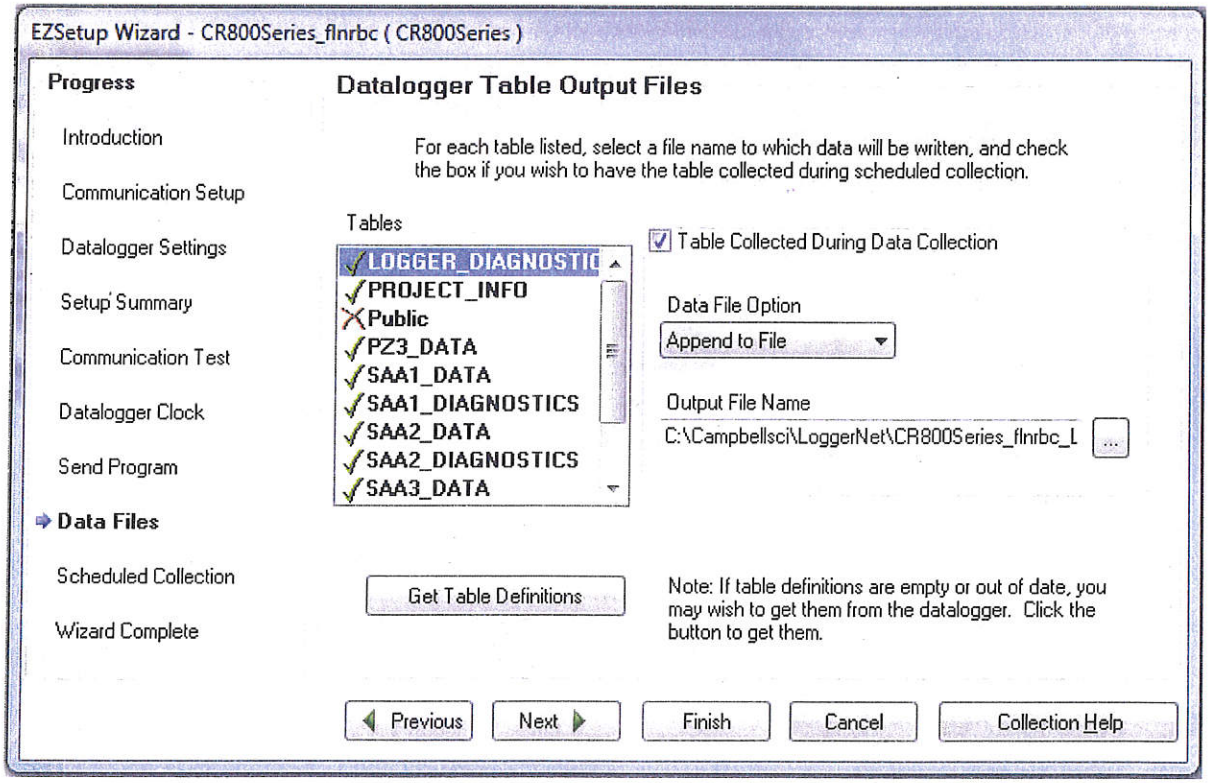


Figure 6.14: Specifying the destination of data files using the LoggerNet Setup utility

Note: Before a new project begins, any CR1000 data files residing in the output file directory should be removed. Otherwise, data from the new project may get concatenated to the existing data file, causing abnormalities in the results.

6.3 *Collecting Data From the CR1000*

6.3.1 Manual Data Collection

For each setup, the PROJECT_INFO, SAAx_DATA, SERIAL_ERRORS, LOGGER_DIAGNOSTICS, and SAA_DIAGNOSTICS data files must be recorded. Data files scheduled to be collected are listed in the 'Data Files' tab of the Setup utility and have a green 'check mark' next to them. Data Tables "Public" and "Status" are not required for data collections as they only store one record of data at a time. They are used only for real time viewing. Ensure that these tables are not selected for Scheduled Collection by de-selecting the 'Included for Scheduled collection' option for that table.

Until data collection is properly configured, scheduled data collection should be disabled. This is accomplished by unchecking the 'Scheduled Collection Enabled' checkbox in the Schedule tab of the LoggerNet 'Setup' utility (Figure 6.15). Data can only be collected now by forcing a data download in the LoggerNet 'Connect' utility by clicking on 'Collect Now' (Figure 6.16).

Whenever the CR1000 is connected using the 'Connect' utility in LoggerNet, the station's clock time should be checked to ensure that valid time stamps are being applied to the data. Correct time stamps cannot be easily recovered from erroneous values. The CR1000's clock is set by clicking on 'Set Station Clock' in the Connect utility, which will assign the time currently set on your PC to the CR1000.

Note: If your PC is using Daylight Savings Time, take care NOT to disrupt the time setting currently employed by the CR1000. If the station clock is adjusted to match Daylight Savings Time on your PC, gaps or overwrites in the data file will occur.

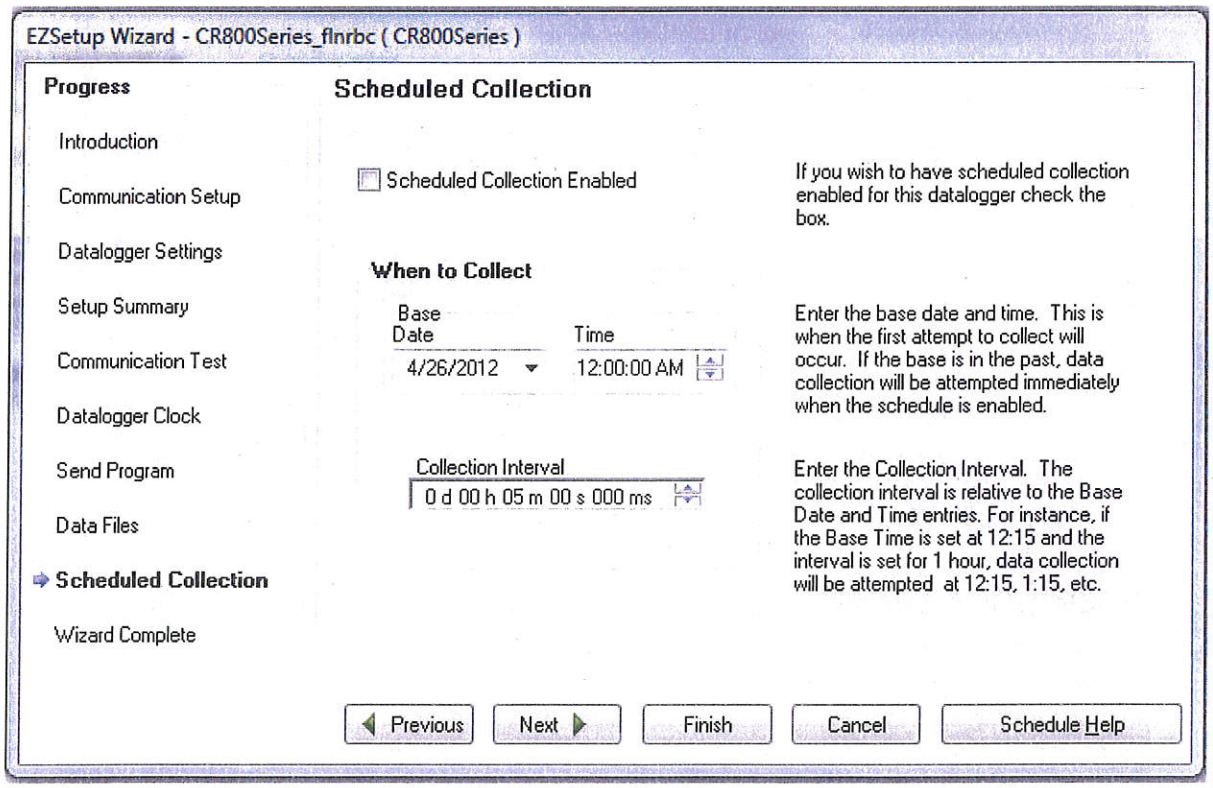


Figure 6.15: Disabling scheduled data collection.

Once sufficient time has elapsed to ensure that data has been collected from the SAAs (based upon the reading frequency), data can be manually collected by clicking on 'Collect Now' in the Connect utility. A summary of the data collected is summarized as illustrated in Figure 6.16.

Note: Data is collected based upon scheduled interval, not upon elapsed time since the program was started. If the program is written so that data is collected every 30 minutes and it is 29 minutes after the hour, data will be collected in 1 minute. If it 31 minutes after the hour, data will be collected in 29 minutes.

6.3.2 Automated Data Collection

Once the manual data collection process has been tested, the data collection process can be automated by specifying the desired data collection interval in the 'Schedule' tab of the LoggerNet 'Setup' utility (Figure 6.17). Check the 'Scheduled Collection Enabled' checkbox. As long as the destination CR1000 is connected (wired or wirelessly), data will be downloaded to the Output File Directory. The Campbell Scientific Raven X manual provides details of configuring a wireless connection with the CR1000. The Campbell Scientific LoggerNet manual provides details of configuring a connection with the CR1000 using a land line. A trial test should always be conducted before beginning a project to ensure that the system is performing as expected.

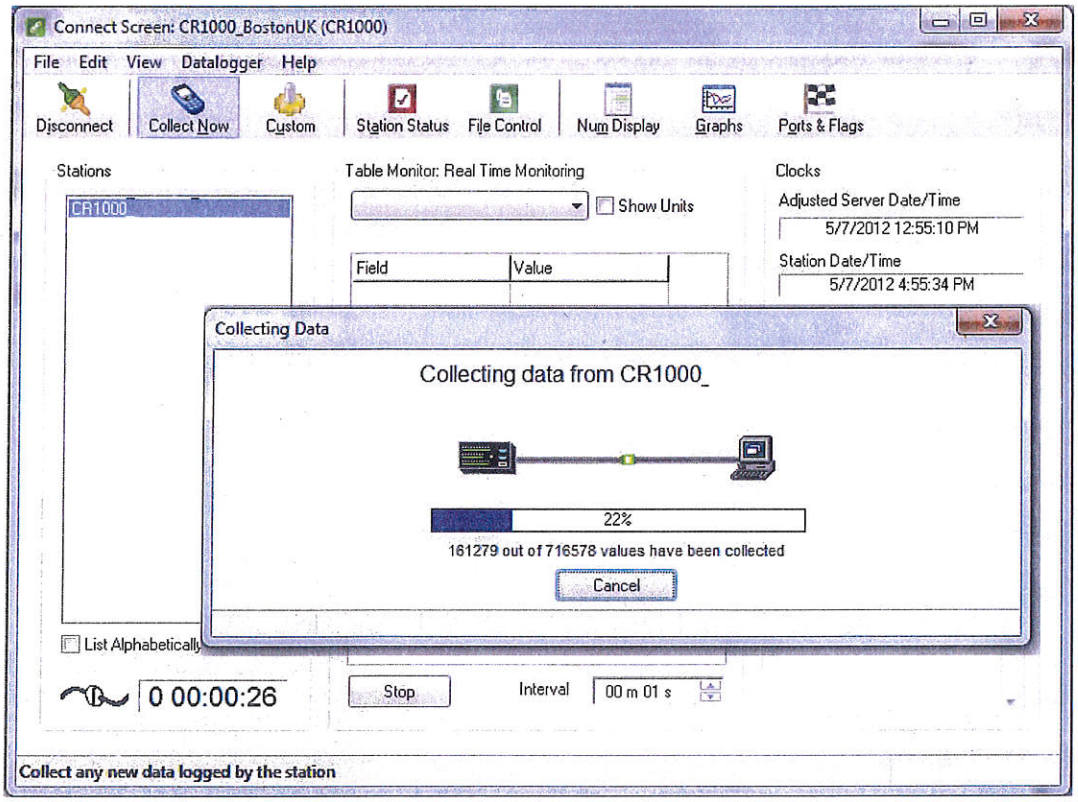


Figure 6.16: Collecting data using the LoggerNet 'Connect' utility.

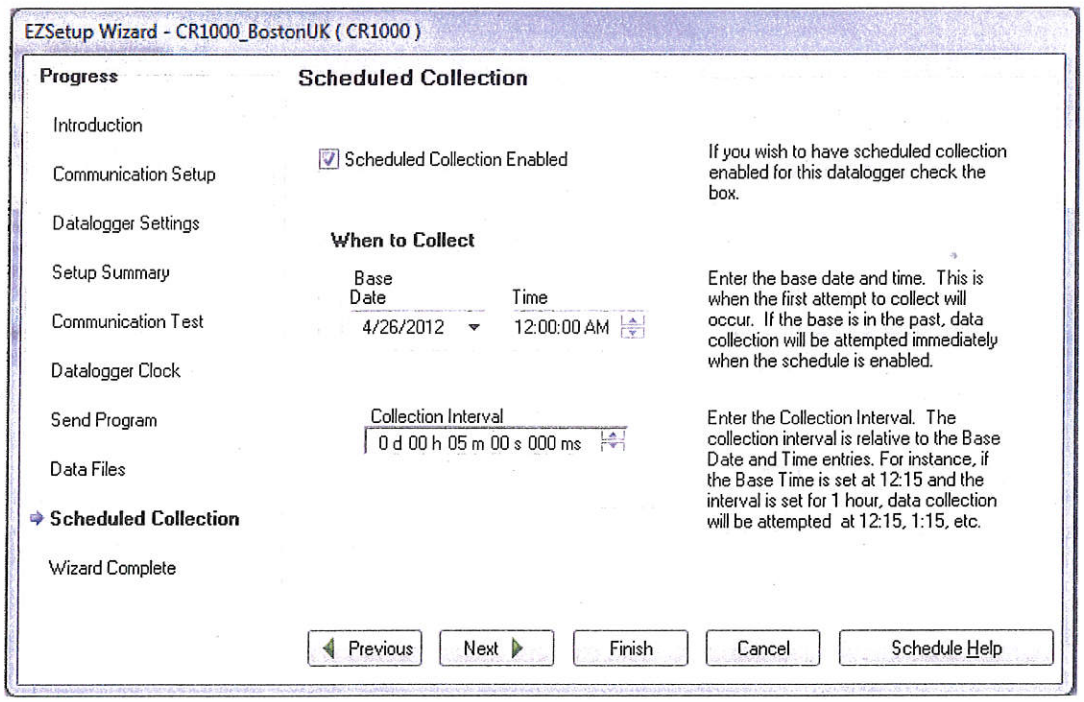


Figure 6.17: Enabling scheduled data collection.

6.3.3 Manual Data Conversions

It is possible to use the SAACR_raw2data utility to convert SAA data, and data from the following instruments: vibrating wire piezometers, strain gauges, and vibrating wire earth pressure cells. It is also possible to convert multiple SAAs into one long "superset" SAA. In order to use these functionalities you will need to create a site file for the project and place it in the appropriate SAARecorder folder (c:\Measurand Inc\SAARecorder\Calibrations\site\[site filename]). N.B. if the site folder does not exist in the c:\Measurand Inc.\SAARecorder\Calibrations folder, you will need to create it to save your site files there. You will also need to place the calibration files for the other instruments into the appropriate SAARecorder calibrations folder (c:\Measurand Inc\SAARecorder\Calibrations\non_saa_coeffs). For more information on these aspects and how to use the converter, please refer to the SAACR_raw2data Manual.

Once the conversion is completed, you will be prompted on whether or not you want to view the data using SAAView.

6.3.4 Automated Data Conversions

Automated data conversion requires generating a pref_project.txt file. This can be done in two ways. This first way does not require having any raw data for conversion. In this case, the Conversion Config Utility in SAASuite can be used to generate the pref_project.txt file which contains conversion settings needed when converting data automatically. An example of a simple file set-up is shown in Figure 6.18. Detailed information on the Conversion Config Utility options are provided in the SAASuite Manual.

Once the pref_project.txt file has been generated, it is possible to set up the computer to automatically convert the data into a format viewable in SAAView. This is accomplished using the LoggerNet 'Task Master' utility.

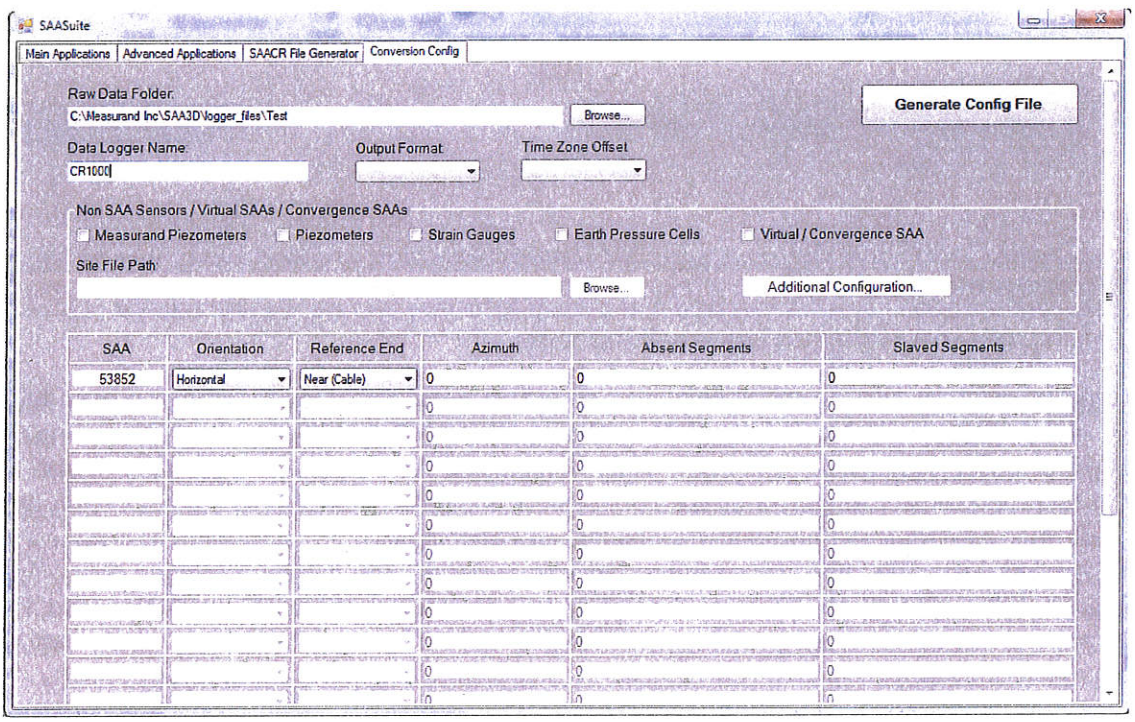


Figure 6.18. Example of pref_project.txt set-up being completed in Conversion Config utility

To add a task in the Task Master, click on the CR1000 of interest, and click the 'Add After' button. Under 'How Task_n Starts', in the Station Event Type, select the 'After Successful Call' Option (Figure 6.19).

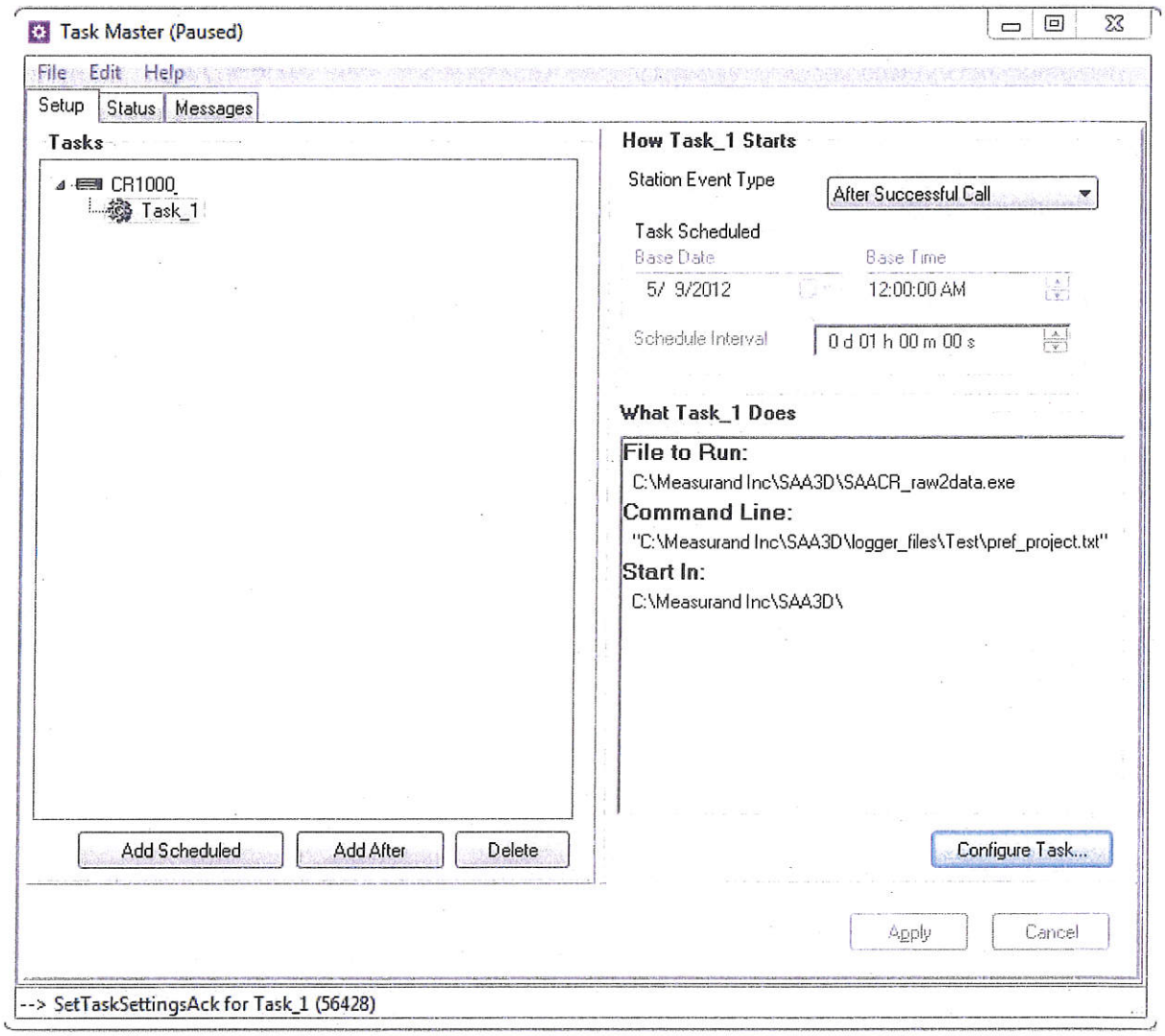


Figure 6.19: Creating a task using the LoggerNet 'Task Master' Utility.

To configure the task, click on the 'Configure Task' button. Once the configure screen is open (Figure 6.20), check 'Execute File' and browse to C:\Measurand Inc\SAA3D\SAACR_raw2data.exe (or the appropriate folder containing this file). Under 'Command Line Options' you must specify the pref_project.txt file that was generated was completed. It should be located in the same directory as the raw data. This entry must be surrounded by double quotation marks (" ") since there is a space in the C:\Measurand Inc\ path. This file contains settings necessary for SAACR_raw2data to complete subsequent conversions. Under 'Start In', enter C:\Measurand Inc\SAA3D\. Select 'Run Minimized' if you don't want to see the application running when it gets called. Hit 'Apply'. The Task Master will now automatically convert raw data that is scheduled to be collected using the LoggerNet 'Setup' utility.

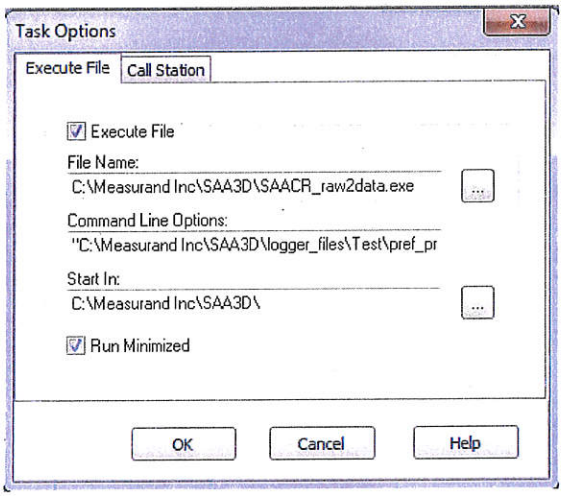


Figure 6.20: Configuring task options in Task Master.

Note: The path name to the pref_project.txt file must be surrounded by double quotation marks since there is a space in C:\Measurand Inc

Verify that the 'Pause All Tasks' check box under the Status tab of the Task Master utility is unchecked, Figure 6.21. The SAACR_raw2data utility will now run upon successful completion of a scheduled data download. A progress bar will now appear after a scheduled data download indicating that the SAACR_raw2data utility is running. If any of the files required by SAACR_raw2data are open while the program is being executed an error message will be generated. Data can be viewed at any point by running SAAView and viewing the most recent data which has already been automatically converted.

Note: Any of the files required by SAACR_raw2data (e.g., calibration files, multi_saa_allcart.txt) cannot be open while the process is running. Otherwise an error will be generated.

It is also possible to create the pref_project.txt file following a manual conversion of the data. In this case, it is necessary to collect and convert data manually at least once to create the pref_project.txt file. The file is then used in task master as described previously to set up automated conversion. The procedure for automating the data conversion process in this case is:

a. Disable scheduled data collection in the LoggerNet 'Setup' utility
b. Send program files (both main and SAA_Include) to the CR1000
c. Set the path for data files in the LoggerNet 'Setup' utility
d. Manually download the data from the logger and perform a manual conversion. This will generate the required pref_project.txt file.
e. Setup a new task using the Task Master utility (previously described)
f. Manually download the data again.
g. Enable scheduled data collection at the desired data collection interval.

If you do not follow this procedure you run the risk of having data gaps.

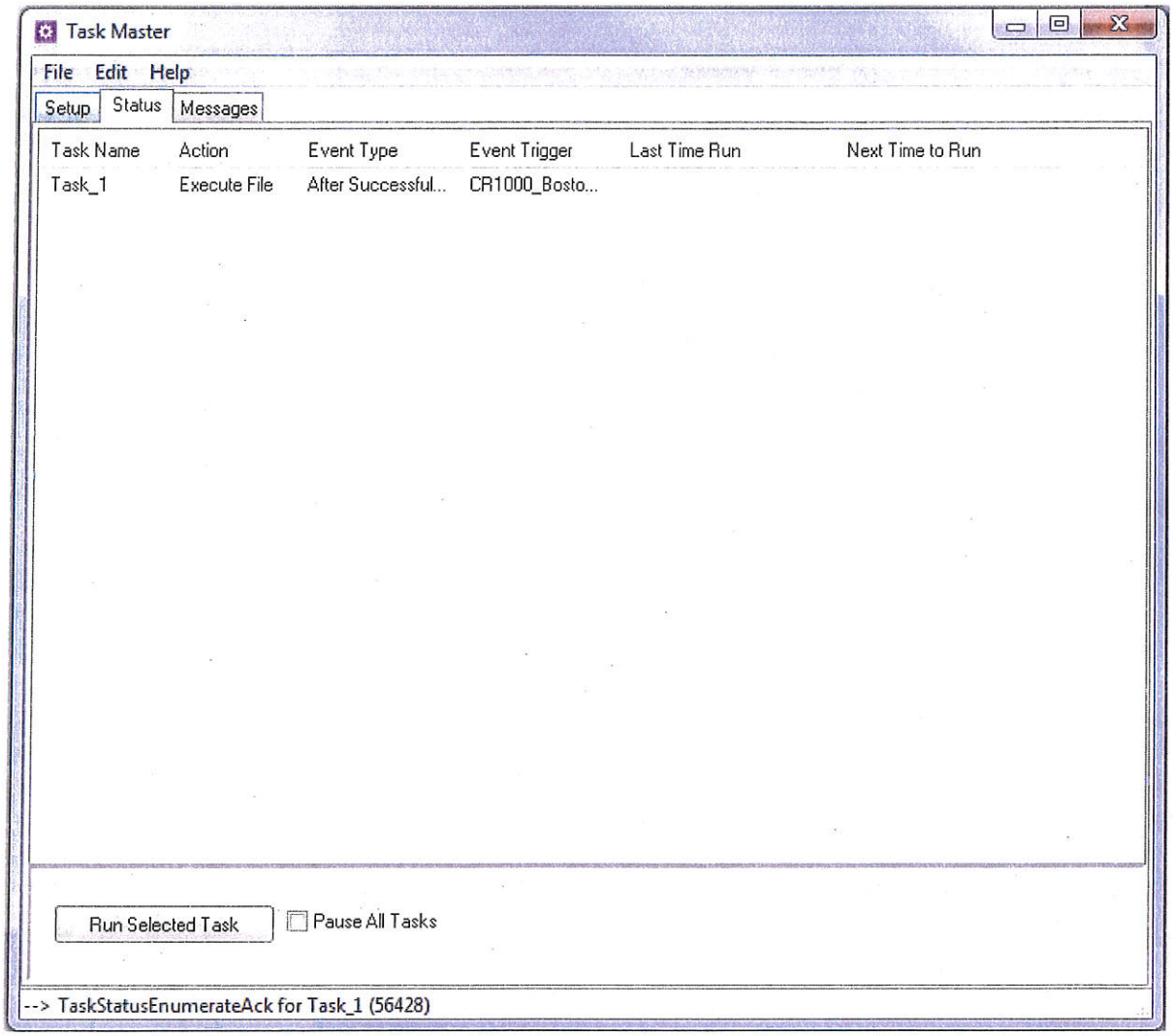


Figure 6.21: Viewing the status of scheduled tasks in Task Master.

6.3.5 Saving Data in Overwrite File Mode

If data is to be collected over long time periods, eventually the SAA data files will become very large and require an increasing amount of time to process. Once the automated data conversion process has been setup, it is possible to switch the File Output Option to 'Overwrite Existing File' (Figure 6.22) for the SAA data files (the PROJECT_INFO, SERIAL_ERRORS, LOGGER_DIAGNOSTICS, and SAA_DIAGNOSTICS files should NOT be changed). The SAACR_raw2data program will recognize that only the most current data is being collected. This data will be appended to the multi_saa_allcart.mat file so that a complete data history is maintained. The multi_saa_allcart.txt file (text file of all Cartesian coordinate records) will no longer be updated in this mode, just the multi_saa_curcart.txt (text file of most recent Cartesian coordinate records).

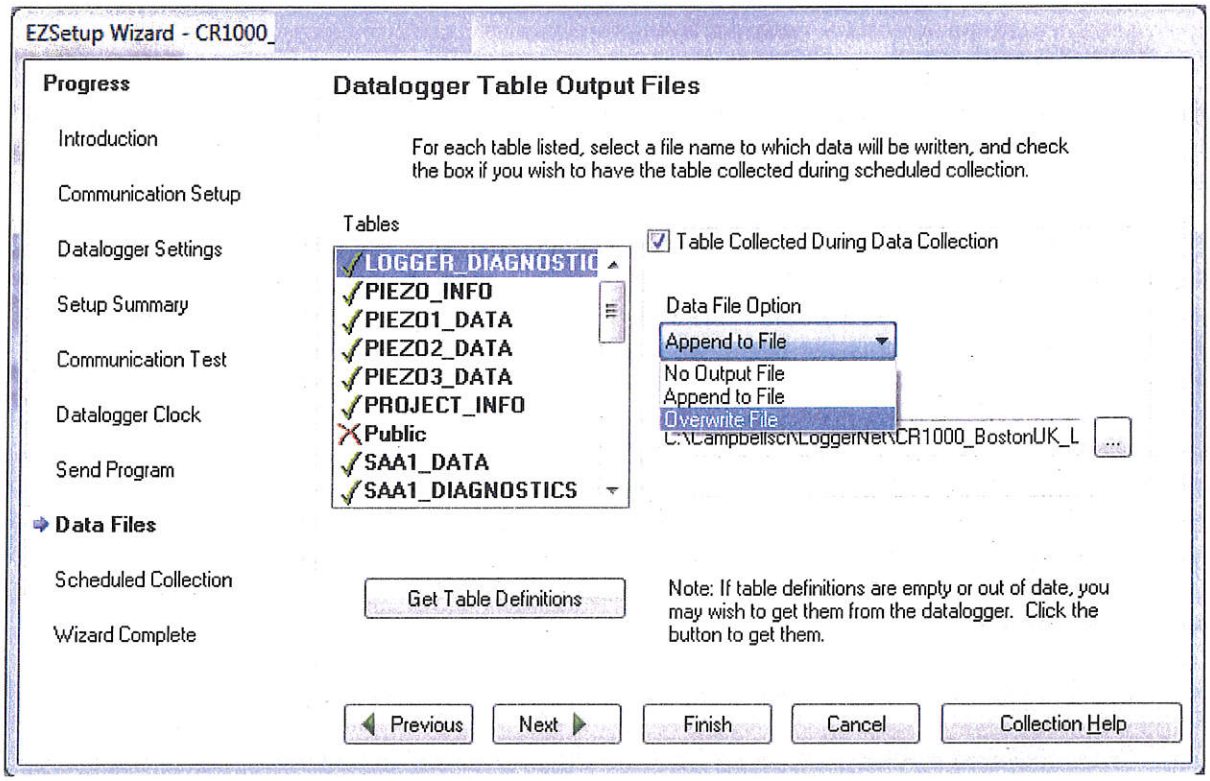


Figure 6.22: Switching the "Data File Output" option in the LoggerNet 'Setup' utility to 'Overwrite Existing File'.

If the SAA Data file is viewed when 'Overwrite File' is implemented, only the most recent data records will be contained in the file.

7. Viewing SAA Data

Once data has been converted to multi_saa_allcart.mat format, it can be viewed using SAAView. Complete instructions on how to use SAAView are given in the SAAView Manual, which can be found in the SAASuite.

After setting up a monitoring station, it is sometimes helpful to look at the absolute shape of the SAA in the ground. To do this, open SAAView and select the SAA you wish to view (Figure 7.1). To look at the absolute shape of the SAA, click on the 'QuickView' button. This will open the window shown in Figure 7.2. The 3D shape of the SAA is plotted on two graphs, the second plot showing the orthogonal view of the first one. It is possible to view the X-Z position data plot and the Y-Z position data plot by clicking the X button at the bottom right of the screen (Figure 7.2). It is also possible to view the X-Y position data plots by clicking on the Z button at the bottom right of the screen. The plots shown in Figure 7.2 contain three solid lines. These are: a blue line representing the initial shape reading of the SAA, a red line representing the latest shape reading, and a black line representing the difference between the initial and latest readings. In order to view intermediate readings, you will need to use the 'ViewUnfiltered' or 'ViewFiltered' option in the main menu. Complete instructions for the use of SAAView are provided in the SAAView Manual.

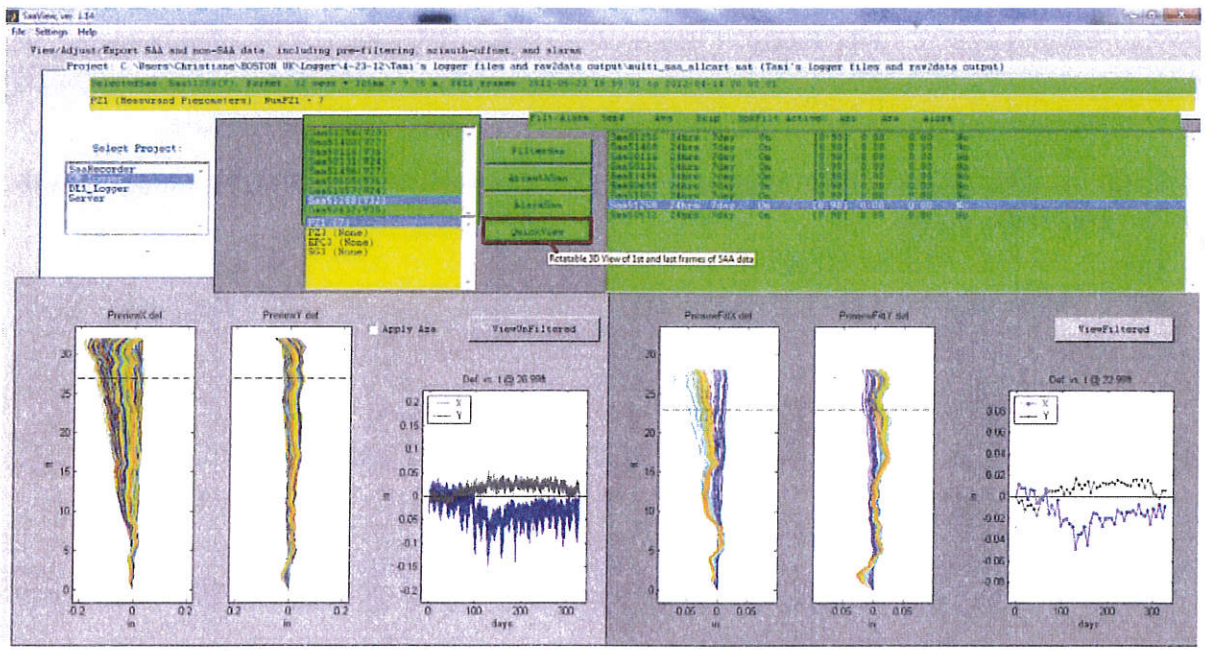


Figure 7.1: Selecting an SAA to View in SAAView.

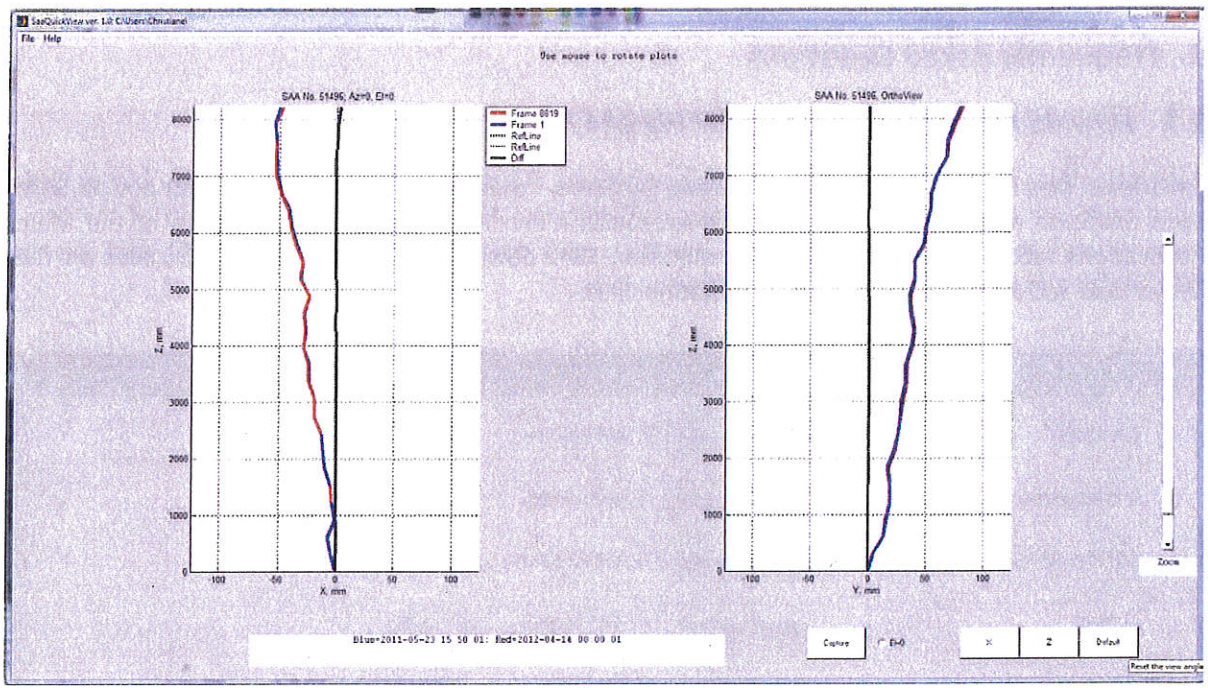


Figure 7.2: Quickview of absolute shape plots for SAA in SAAView.

8. Frequently Asked Questions

8.1 *How do I get calibration files for my SAA?*

Calibration files for SAA are downloaded using SAASuite. To download the files when you buy an SAA, open SAASuite and click on the "Get Software/Calibration Files" button at the bottom of the Main Applications tab. Once in the Software/Calibration Files download window (Figure 8.1), click on the "Download and Install" button next to Calibration Files.

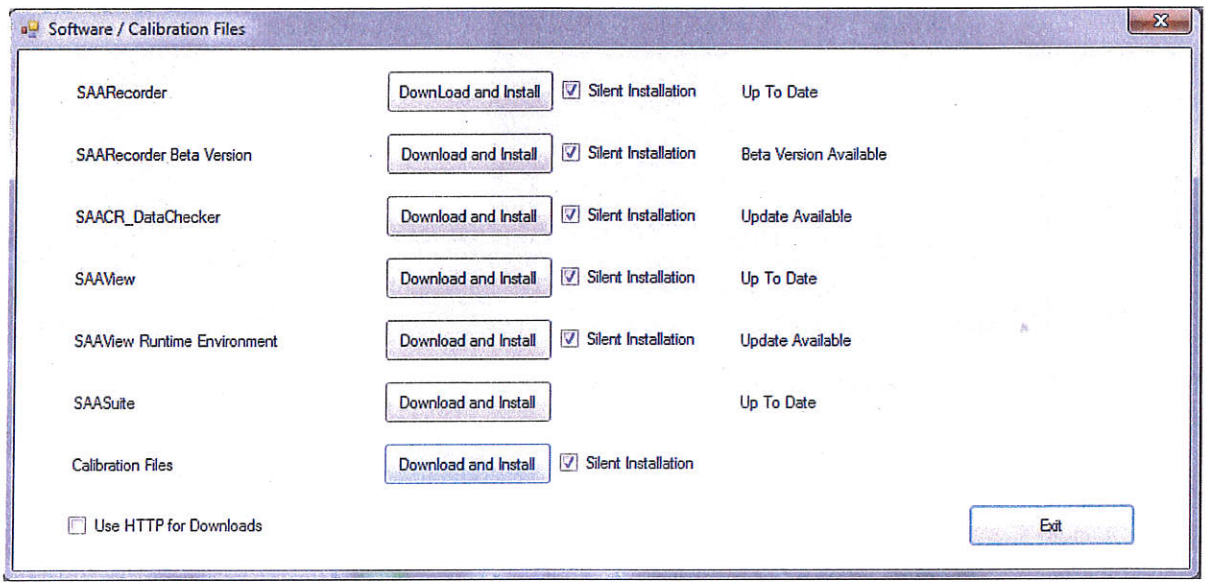


Figure 8.1. Software/Calibration Files download window.

8.2 *How do I check for, and get software updates?*

To check for software updates, click on the "Get Software/Calibration Files" button at the bottom of the Main Applications tab in SAASuite. Once the Software/Calibration Files download window is open, look at the far right column to check the software status (Figure 8.1). Software will be listed as either "Up to Date" or "Update Available". For beta versions of software, the message will remain "Beta Version Available". To update software utilities, click on the "Download and Install" button next to the software you wish to update.

8.3 *I am having problems connecting my SAA to SAARecorder. How do I check the connection?*

Check the following items:

1) Check which COM port the SAA is connected to. To do this, close all boxes open in SAARecorder and select "Communications | Check available COM ports". This will show you a list of the serial COM ports currently available. Unplug the USB to serial converter and repeat the action. The list will have decreased by one port, this is the port which the SAA interface is using. Connect the

USB to serial converter to the same USB port and make sure to only select this port when you search for Serial SAAs.

2) Check to make sure that the +12V power is properly connected to the SAA interface. For the SAAUSB, make sure that the +12V power supply is plugged into the SAAUSB and the mains power. For SAA232s or SAA232-5s make sure that the +12V and ground ports on the logger is connected to the red and black pins in the 4 pin connectors. Do not use the SW12V power port to supply power to the SAA since this port could be turned off. If you are using an SAAFPU, make sure that the unit is fully charged using a multimeter.
3) Check that the SAA connector is properly wired and/or seated to the interface. For the 4 pin round SAAF connector, check for cable damage behind the connector.
4) Check to see if the LED on the SAAUSB interface is lit.
5) Check that the driver for the USB to serial converter has been installed and is up to date. If you are not sure, re-install SAARecorder. Once this is done unplug the USB to serial converter and plug it back in to the same port. You may need to reboot your computer for the driver installer to finish the installation. If so, disconnect the SAA and SAA power, unplug the USB to serial converter, and restart the computer. Once finished, make sure to connect the SAA and SAA power as well as the USB to serial converter. Note that it will sometimes take a few minutes for the USB driver to be installed. Check the System Tray at the lower right corner of the Windows Desktop to verify the installation progress.
6) In some cases the USB to serial converter can crash. Try to disconnect the USB to serial converter from the computer, and disconnect the SAA and SAA power from the interface. Wait 5 seconds. Plug the USB to serial converter into the USB port and wait another 5 seconds. Connect the SAA to the interface, then connect the SAA power. Try to search for serial SAAs again.

8.4 *How do I diagnose an unresponsive SAA for cable damage?*

Disconnect the SAA cable from the interface and use an ohmmeter to check the cable for shorts or opens. Typical SAA cable resistance values are given in Table 8.1. The pin numbering convention for the 4-pin SAAF Connector is shown in Figure 8.2

Table 8.1 Typical SAA cable resistance values.

Wire Pairing	Pin Pairing on 4-pin SAAF Connector	Resistance (kΩ)
Black to White	Ground - 1	4 to 9
Black to Blue	Ground - 2	1 to 3
Black to Red	Ground - 3	1 to 3
Black to Shield	NA	< 0.05

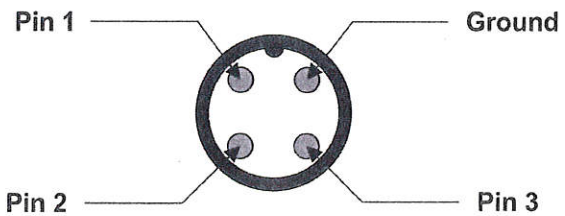


Figure 8.2. Pin numbering convention for the 4-pin SAAF Connector. Note the reference point at the top of the connector.

Actual readings will vary, but it is important that they are not under 50 Ω (except for black to shield), which indicates a short, or over 20 kΩ, which indicates an open.

If a failure is found with the 4-pin round connector, inspect the wiring inside the connector to make sure that no wires have been broken.

8.5 How do I wire the SAAF Connector onto the SAA cable?

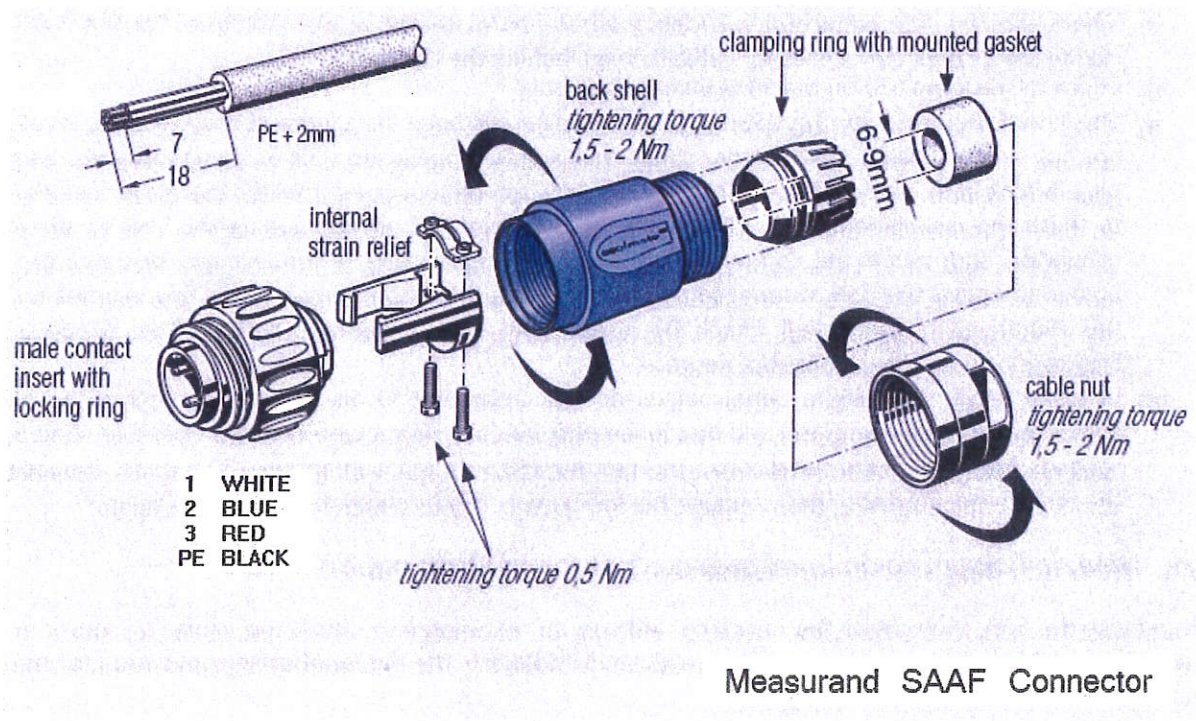


Figure 8.3 Wiring information for Measurand SAAF connector.

8.6 How do I check my magnetometers to make sure they are working properly?

Note the information provided in this section only applies to SAAs for which optional magnetometers were ordered.

8.6.1 Checking magnetometer data collected with SAARecorder

If you are using SAARecorder to collect data, you can view magnetometer data for all of your magnetometer devices by clicking on the 'Data and graphs | Magnetometer data ' menu item. This presents a window that allows you to quickly view heading information and total magnetic field magnitude for each magnetometer. If the devices are functioning correctly and the SAA is not moving, and is either vertical or within 45 degrees of vertical, the X-axis heading values should remain relatively fixed (within +/- 1 degree) and should also agree fairly well (within +/- 5 degrees) with one another, assuming that the twist along the length of the SAA is not excessive. In the absence of any magnetic interference, the magnetic field strength measured by each device should agree with the other devices to within +/- 5%.

8.6.2 Checking magnetometer data collected with a data logger using SAACR_raw2data

If you are converting data logger data using SAACR_raw2data, you will need to:

1. In the "Settings" window of SAACR_raw2data, press the "Advanced (mag)" button.
2. Press Continue.
3. Choose or create a file to which magnetometer data will be saved, ex: magdata.mat.
4. Open the same file you just saved.
5. Press the "Specific Settings" button.
6. Should see an Azimuth vs. Time graph with a single trace of "Change in Azimuth" for each magnetometer.
7. If the SAA is stable (i.e. not being rotated or moved at all, and none of the magnetometers are affected by magnetic interference) then the change in azimuth plots for each magnetometer should remain quite close to 0 degrees. Significant changes from 0 degrees (i.e. more than +/- 1 degrees) would indicate that either (i) the SAA was rotated or (ii) there was some magnetic interference acting upon the magnetometer(s).
8. Check the total magnitude of the magnetic field measured by each magnetometer by clicking on the "tot" button in the top-right corner and looking at the magnitude traces. The value of these traces is calibrated to be 1.0 for the Earth's magnetic field as measured at our factory located in Fredericton, NB, Canada, but will in general be slightly different depending on the strength of the Earth's field at your location. For example, in many parts of South America, the average strength of the Earth's magnetic field is only about half that of the magnetic field strength in Eastern Canada. If the total magnitude measured by one or more magnetometers differs from that of the other magnetometer(s) by more than 10% then it is likely that there is some magnetic interference near the SAA that is adversely affecting one or more of the SAA magnetometers. It is generally advisable to "turn off" any magnetometers that are affected by magnetic interference by right-clicking on their corresponding magnitude trace and then selecting the "Turn Off this mag" option.
9. After the on / off states of the magnetometer devices and a "quiet time" in the magnetometer data have been selected (as described in the "Magnetometers" section of the SAACR_raw2data documentation) the user saves the magnetometer file typically in a subfolder of the main data folder called "magdata". Within this folder is a generated file called "headings.txt" which contains a summary of the heading azimuth angles measured by each magnetometer. These headings are useful for gauging exactly how much the SAA might be twisting.

8.7 How do I check my SAAF for twist?

SAAs are delivered on a reel, with dots on the SAA facing out from the reel. This is your assurance that the SAA is properly reeled and will be free of twist. If a reel stand is used and the SAA is unreeled directly from the reel into its conduit while being allowed to rotate within the conduit, it will not be twisted in the conduit. All portions will point at the same azimuth direction. This can be verified by using the X-marks and on-reel dots on the SAA (Figure 8.4).

If using SAA+PVC installation methods, then the presence of twist can be checked by looking at the X-marks on the near and far end of the SAA and verifying that they are both pointing in the same direction. As shown in Figure 8.4, the on-reel dots all face outwards when the SAA has been properly reeled.

Figure 8.4. X-marks vs. On-reel dots. X-marks are long straight lines normally found at the near and far end of the SAA. On-reel dots are dots found on every 8 or 10 segments on the SAA.

When the SAA is unwound into its conduit, the on-reel marks will rotate and no longer be facing the same azimuth. This is expected and does not indicate that mechanical twist has occurred. It instead indicates that the joints are returning to their factory calibrated headings. To check for twist in an SAA installed in a pre-cased borehole follow the steps below.

1. Place the SAA reel on a reel stand near the borehole. It should be oriented so that the bottom segment of the SAA can be unreeled directly from the top of the reel into the borehole.

2. Make sure to carefully record the on-reel orientation of the SAA so that it can be returned to the same state with the marks facing out. Photographs are recommended.

3. Unreel the SAA into the borehole from the reel, making sure not to apply torsion to the SAA. Allow the portion going into the borehole to rotate freely.

4. Lift and rotate the SAA to achieve the desired azimuth, but ONLY if it is free to rotate in the hole. If the SAA is not free to rotate at this stage, DO NOT rotate it. If the SAA includes magnetometers, take the azimuth readings using SAARecorder. The readings will be used for comparative purposes only, and not to set the azimuth of the SAA.

5. Lift the SAA part-way out of the borehole using the techniques outlined in Chapter 4. Return the SAA to its original heading and begin to reel the SAA back onto its reel in an exact reversal of the unreeling process. Make sure that any marks on the top part of the SAA face the same way as they faced when the SAA was on the reel.

6. Complete the reeling process taking care to align all the segments carefully next to each other, with the joints all in line with each other.

7. At the end of the reeling process, the on-reel dots should all still face the same direction. If they do not all face the same direction, then twist has been induced. Please review your procedure and consult with Measurand.

8.8 *Why is my data logger missing samples?*

In most cases, missed samples are due to issues with either the reading interval or logger power.

Collecting data from multiple instruments can take a significant amount of time. If the logger is in the process of collecting data when the next sampling interval comes around, it will ignore the new request for samples and complete its current data collection. It will then collect again when it receives another request for samples at the next available interval. In order to avoid this issue, make sure to know how long it takes to collect data from all sensors attached to the logger. See Section 6.2.2 for recommended SAA reading intervals. Note that loggers can collect properly for an extended time, then fail as "housekeeping" functions of the logger accumulate and start competing for logger resources.

If the logger power is too low, it can stop functioning. For loggers which are connected to batteries with solar panels, it is sometimes possible for the battery to be recharged enough for the logger to regain power. If the logger program is set to run on Power-Up, it will resume collecting data but there will be gaps in the data. To avoid this issue, make sure to periodically check the Logger Diagnostics table to ensure that the voltage is above 11.5 V.

8.9 *How do I check data collected using a data logger to make sure it is good?*

Use the CRDataChecker utility in SAASuite to verify the raw data files collected using a data logger are good. CRDataChecker provides colour coded graphs of the SAA data vs. time. Instructions for using the CRDataChecker can be found in the CRDataChecker Manual found on the Advanced Applications tab of SAASuite.

8.10 *I just saved 3 samples of data. Why does SAAView only show one frame?*

SAAView has a default filter which will average several readings together and present these in the Filtered view presented at the right hand side of the main SAAView window. In order to view all data, either change the filter using the methods described in the SAAView Manual, or make sure that you are looking at the data in the unfiltered View located at the left of the main SAAView window.

8.11 *Can I shorten my SAA?*

To shorten an SAA it must be sent back to Measurand. Due to the octet structure, the changes to the calibration required when an SAA is shortened, and the waterproofing systems, it is not possible to shorten an SAA yourself. If you need to shorten the SAA consider instead using the "Turn off/Ignore Segments" option available in SAARecorder or SAACR_raw2data.

8.12 *How do I turn off or ignore segments?*

In some cases the SAA in not fully installed into a borehole. In these cases, it is possible to turn off segments and ignore them in the data viewer.

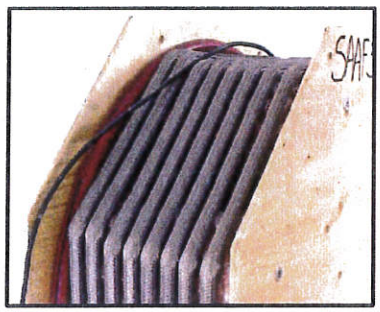
8.12.1 Data collected using SAARecorder

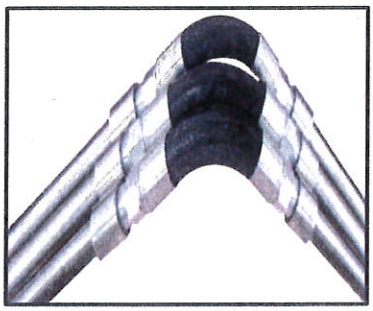
To turn off segments in SAARecorder, select 'SAA Setup | Advanced | Turn on/off section of SAA'. This will open a text box in which you can enter the numbers of the segments you wish to turn off.

8.12.2 Data collected using a data logger

In order to turn off segments for data collected using a data logger, you must use SAACR_raw2data. In the Settings window, enter the segment numbers you wish to turn off in the "Turn Segment Off" box.

A. SAA Life-Extension





SAA Life-Extension

(Of particular importance to "Scanners": those who run SAA in and out of holes frequently)

Note: This document is additional to, and does not replace, the SAA Installation Guide or SAA Manual.

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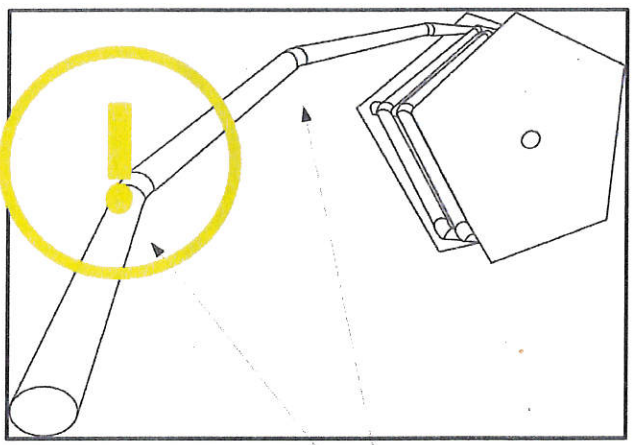

SAA comes on a reel.
Joints have elastic limits.
Coverings can be abraded.
Segments can be bent.
Care is required!
Please read on...

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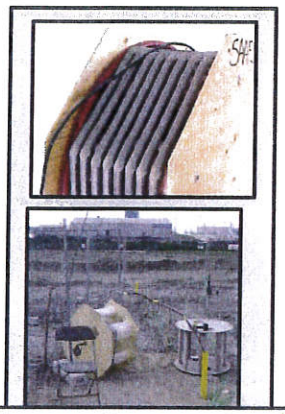

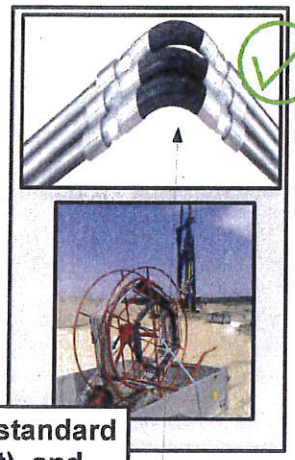

These instructions apply to either standard SAAs (on left) or SaaScan (on right), and are particularly important for "Scanners" (customers repeatedly measuring holes or drill strings).

Scanners: Please use SaaScan. Lifetime will be greatly extended, and twist much less likely.

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All SAAs have X marks (left) at both ends.
Most SAAs have DOTS facing out from the reel.
Some SAAs have extra X marks, such as on each segment.

What do they mean? Please read on...

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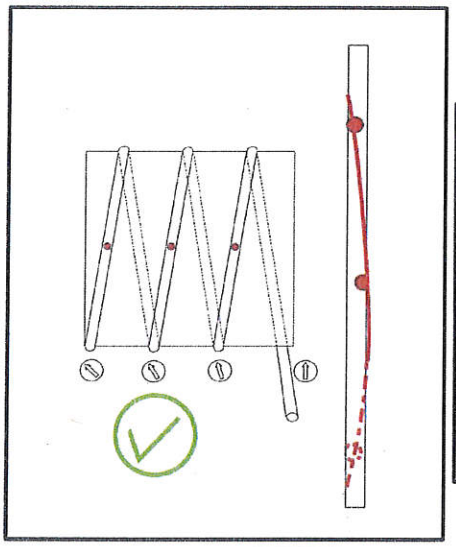

DOTS on a reel should face out.

When the SAA is un-wound and straight, the dots will NOT BE LINED UP. They will precess around the circumference of the SAA. They are ONLY for checking that the SAA is properly wound, without twist.

(For more information on marks, see the SAA Installation Guide).

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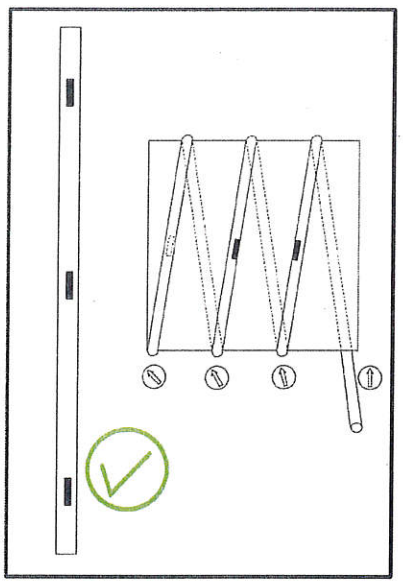

X Marks on a straight SAA should always line up. If they do not, the SAA is twisted.

When the SAA is wound on a reel, X Marks will precess around the circumference of the SAA and will NOT LINE UP.

X Marks are only for checking that a straight SAA is not twisted.

(For more information on marks, see the SAA Installation Guide).

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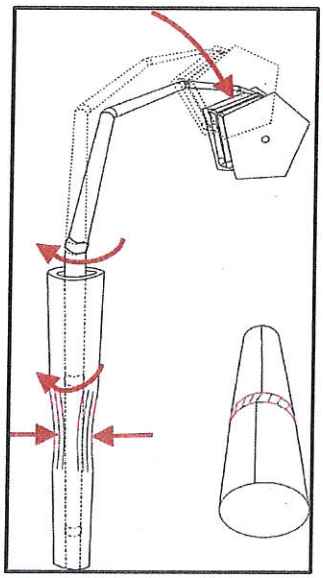

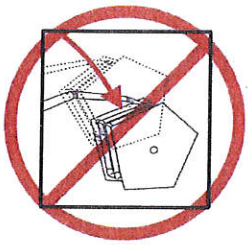

Classic bad practice:
If you move the reel with SAA in the hole, friction or a tight spot down-hole can cause large torsional moments on the joints and twist them beyond their elastic limits.

Don't do it!!

It is better to place the SAA, sight on its top X mark, and use the sighting data to correct the azimuth in software.

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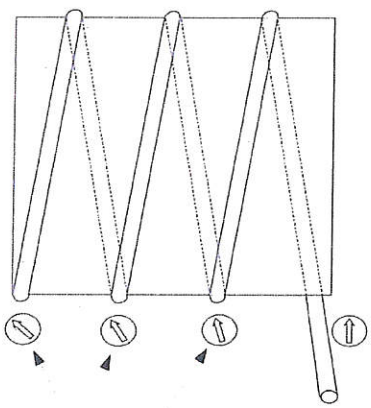

Reversible "Twist"

Anything (cable, rope, SAA) wound on a reel takes on a low-stress "twist" during winding.

During un-winding, the twist comes back out.

To avoid adding excess twist during winding and unwinding, allow the straight part of the SAA to rotate freely.

Any "added" twist will not "come back out"! (see also next slide).

(Winding pitch is exaggerated here. Always minimize spaces between SAA turns, in exactly the "factory-wound" format!)

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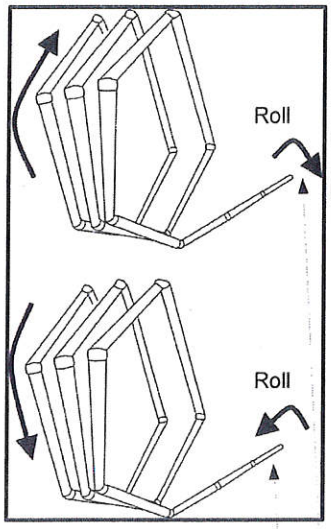

During winding, the SAA must be allowed to rotate about its axis ("roll") as it goes on the reel.

During un-winding, the SAA must be allowed to rotate about its axis as it comes off the reel.

Always allow rotation, and you will not induce twist beyond the elastic limits of the SAA!

Do not hold tightly!!

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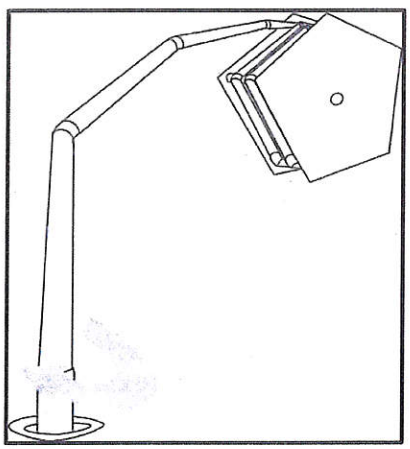
03/07/2013



The foregoing means: As you unreel an SAA into a hole, it will rotate! The X marks will rotate with it.

Allow this to happen. When the SAA is at its final position, THEN use the X marks to align its azimuth or if there is any obstruction, SIGHT on the X marks and use an azimuth offset in the software.

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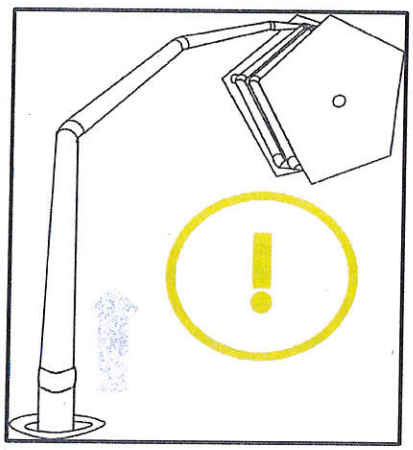
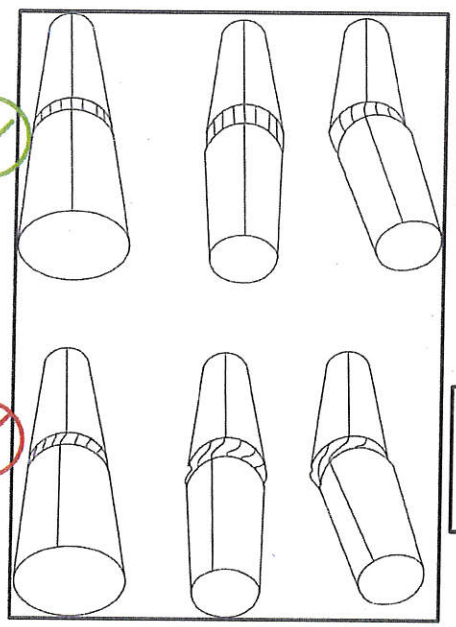
03/07/2013



If you MUST adjust the azimuth of an SAA (not recommended especially if reel is attached), lift it from the bottom of the hole and ensure it is free of any friction. Then very carefully move the reel.

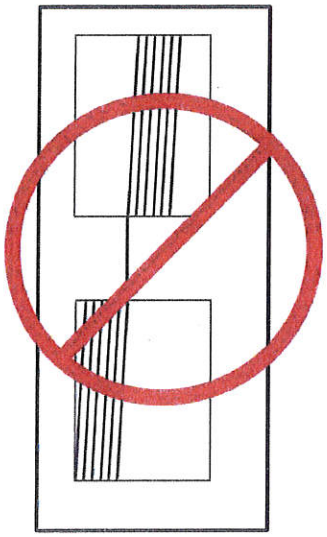
measurand ShapeAccelArray SAA 03/07/2013



Joint: Straight, bent down, and bent down going on reel without added twist.

Joint: Straight/twisted, bent down (still twisted), and bent down going on reel WITH added twist.

measurand ShapeAccelArray SAA 03/07/2013



Reel-Reel Transfer:

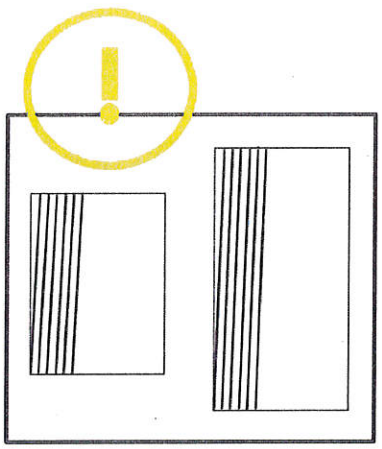
DO NOT DO THIS. Twist is inevitable, even for this "best-case" reel-reel orientation.

Transferring to another reel:

DO unreel onto a polished flat floor and then reel onto another reel. Or unreel/reel using a smooth vertical borehole. Beware of friction. <u>Remember to let the SAA "roll" during reeling/unreeling.</u>

measurand ShapeAccelArray SAA

03/07/2013

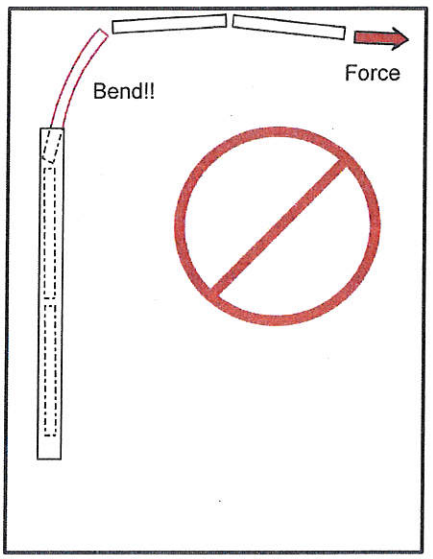


Transferring to another reel:

A change in number of facets on a reel will result in a different pitch of the helix, and hence a different amount of low-stress twist. Do not expect the dots to face properly on the new reel. New dots should be marked on a new reel if it is a different size.

measurand ShapeAccelArray SAA

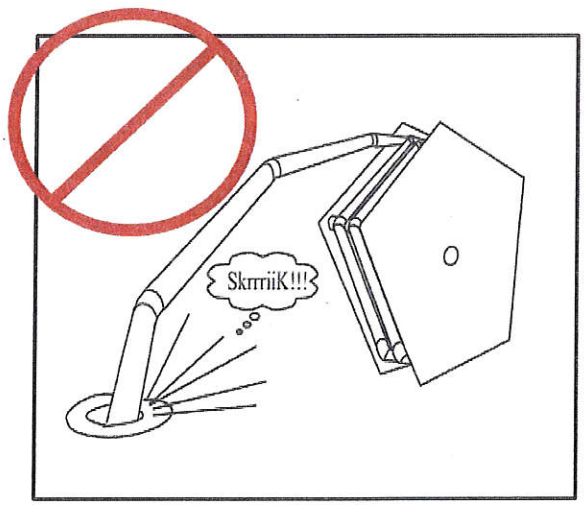
03/07/2013



Avoid bending segments.

Do not apply more than 10 kgf (22 lbs) lateral force to a segment!

measurand ShapeAccelArray SAA 03/07/2013



DO NOT ABRADE segments and joints!!

Build a smooth ramp or "shoehorn" and/or feed into/out of holes with CARE.

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SAA is a precision instrument. It must be treated with care... This one was NOT!

Use a reel stand. Always wind SAA exactly as it was wound at the factory!

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B. Maximum Cable Lengths for SAAs

Note: The maximum cable lengths given below are for SAA with no magnetometers or SAAPZ attached to the cable. If you have either of these, contact Measurand for more information on maximum cable length.

Table B.1 Maximum Cable Lengths for SAAs with 500 mm (19.7") Segments

SAA232iso@13.5V Measurand Cable SKUCAB18 nom		SAA232iso@16.5V Measurand Cable SKUCAB18 nom		SAA232iso@13.5V Measurand Cable SKUCAB14 order		SAA232iso@16.5V Measurand Cable SKUCAB14 order	
SAA m	Cable m	SAA m	Cable m	SAA m	Cable m	SAA m	Cable m
16	1200	16	1200	16	1200	16	1200
20	1000	20	1200	20	1200	20	1200
24	800	24	1100	24	1200	24	1200
28	700	28	1000	28	1200	28	1200
32	600	32	900	32	1200	32	1200
36	550	36	830	36	1200	36	1200
40	500	40	750	40	1200	40	1200
44	450	44	690	44	1110	44	1200
48	400	48	640	48	1000	48	1200
52	350	52	590	52	900	52	1200
56	320	56	550	56	810	56	1200
60	300	60	510	60	730	60	1200
64	270	64	470	64	660	64	1130
68	240	68	430	68	590	68	1040
72	220	72	390	72	530	72	950
76	200	76	360	76	480	76	880
80	170	80	330	80	430	80	810
84	150	84	300	84	380	84	740
88	140	88	280	88	330	88	680
92	120	92	260	92	290	92	620
96	100	96	230	96	250	96	570
100	80	100	210	100	210	100	520

Table B.2. Maximum Cable lengths for SAA with 305 mm (1') Segments

SAA232iso@13.5V Measurand Cable SKUCAB18 nom		SAA232iso@16.5V Measurand Cable SKUCAB18 nom		SAA232iso@13.5V Measurand Cable SKUCAB14 order		SAA232iso@16.5V Measurand Cable SKUCAB14 order	
SAA ft	Cable ft	SAA ft	Cable ft	SAA ft	Cable ft	SAA ft	Cable ft
32	3940	32	3940	32	3940	32	3940
40	3280	40	3940	40	3940	40	3940
48	2620	48	3610	48	3940	48	3940
56	2300	56	3280	56	3940	56	3940
64	1970	64	2950	64	3940	64	3940
72	1800	72	2720	72	3940	72	3940
80	1640	80	2460	80	3940	80	3940
88	1480	88	2260	88	3640	88	3940
96	1310	96	2100	96	3280	96	3940
104	1150	104	1940	104	2950	104	3940
112	1050	112	1800	112	2660	112	3940
120	980	120	1670	120	2390	120	3940
128	890	128	1540	128	2170	128	3710
136	790	136	1410	136	1940	136	3410
144	720	144	1280	144	1740	144	3120
152	660	152	1180	152	1570	152	2890
160	560	160	1080	160	1410	160	2660
168	490	168	980	168	1250	168	2430
176	460	176	920	176	1080	176	2230
184	390	184	850	184	950	184	2030
192	330	192	750	192	820	192	1870
200	260	200	690	200	690	200	1710

C. Marking On-Reel Dots on an SAA

If there are no on-reel dots on your SAA, please make some for your SAA. Place them at every 8 segments for SAAs with 305 mm (1') segments, or every 10 segments for SAAs with 500 mm segments. This way all the on-reel dots will be placed along one facet of the reel. See Figure C.1 below. Use a straight edge and place a dot on the segment where the straight edge meets the segment surface, as shown below. The marks should all face the same direction. Note that the axial position of the dots on each segment will often vary (See photo in Figure C.1). This is not important. However, it is important that the dots all face the same direction.

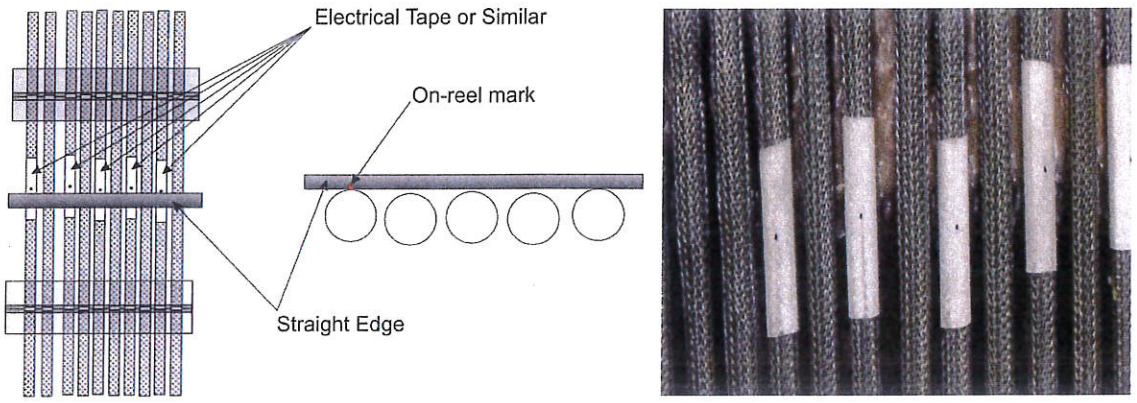

Figure C.1. Marking on-reel dots on an SAA

D. Communicating With the SAA Field Power Unit via Wireless pair

The SAA Field Power Unit comes equipped with a wireless cable replacement feature for use when a wired connection to your PC is inconvenient. The included serial to USB cable, shown in Figure 3.2, can be replaced by a set of two wireless adapters. Note that these adapters work as a pair, and each adapter will only work with its mate. One adapter in the pair is equipped with a 9-pin connector and replaces the Field Unit serial to USB cable. The other adapter is equipped with a USB plug to connect to your PC. These two adapters are "paired" and programmed at the factory and require no user setup. To the PC these adapters look the same as the directly connected cable. A new serial COM port will be installed the first time the SAA Field Power Unit is connected to your PC using the wireless pair. The communication range of the wireless pair is approximately 20 m.

When plugging in the USB wireless adapter, wait for the blue LED in the adapter to stop blinking and become solid. This indicates that the connection to the adapter connected to the SAA Field Power Unit has been established. Once the connection has been established, go to SAASuite and open SAARecorder. If the blue LED continues to blink, make sure that the other adapter is properly connected to the serial cable. Because it is possible to have some interference with the wireless communications, it is necessary to add a timeout in SAARecorder. This is done in the SAARecorder Startup by checking the "Using Serial-to-Ethernet Device" box (Figure D.1). Once the box is checked, it is possible to modify the timeout from the default 500 ms. The recommended range for the timeout is 200 ms to 500 ms.

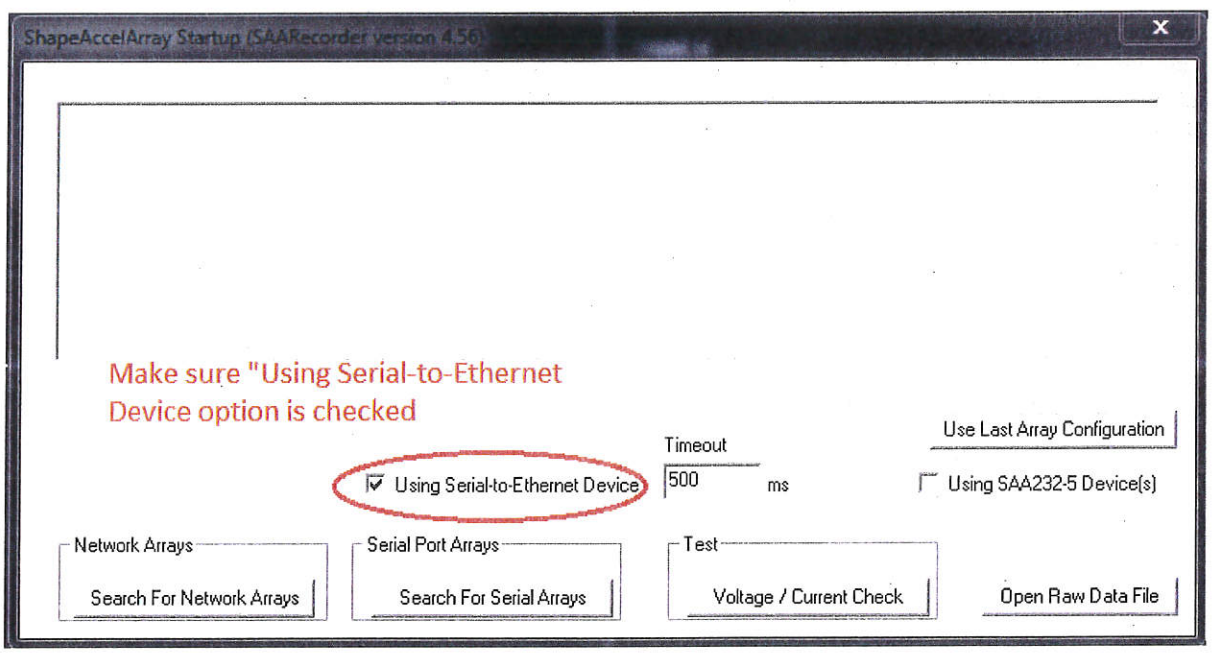

Figure D.1: Adding a timeout in the startup window in SAARecorder.

E. Connecting an SAA to computer running SAASuite using an SAA232

Single SAA can be connected to Measurand's SAA232 interface (shown in Figure E.1). The SAA232 incorporates a resettable fuse and surge protection, and automatically applies power to an SAA only when there is serial RS232 data being sent from the PC to the SAA232. It also converts the RS232 communications protocol from a PC serial port to the RS485 communications protocol that the SAA uses.

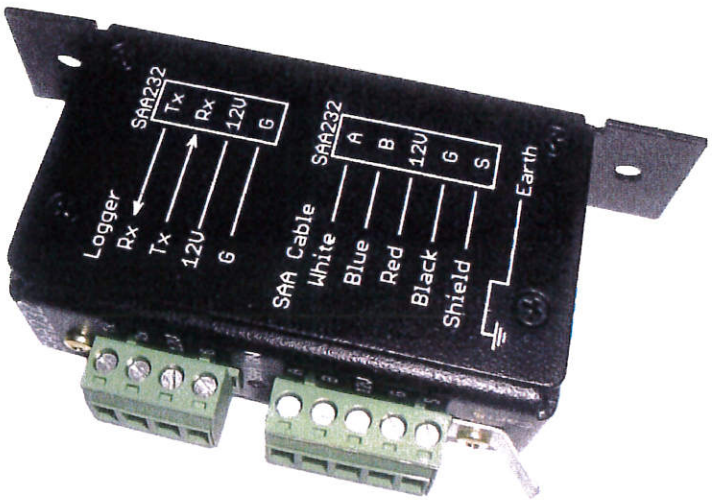

Figure E.1: SAA232. The 4-pin green connector connects to the RS232 port of the computer. The 5-pin green connector connects to the SAA.

The following steps should be taken when using the SAA232 converter with an SAA:

1) Connect the SAA to the green 5-pin connector on the SAA232 (Figure E.1). The SAA wiring is as follows:

Pin 1: White wire (RS485 A)

Pin 2: Blue wire (RS485 B)

Pin 3: Red wire (+12 V to SAA)

Pin 4: Black wire (GND)

Pin 5: Shield

Note: If you are using an older SAA, the wiring may use different colors for the RS485 A and B communications wires, please check with Measurand if you are unsure how to connect these wires.

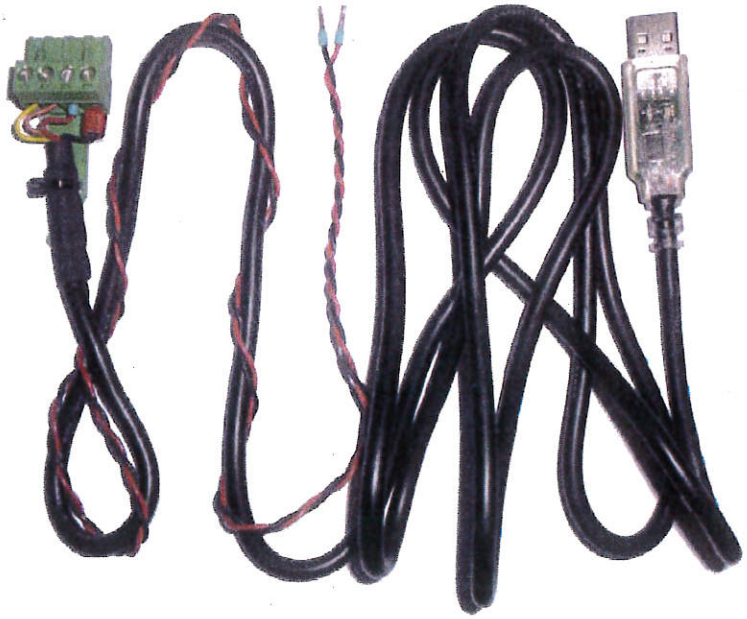

Figure E.2: SAA232-USB cable. This is a USB to serial converter for use with SAA232. The red wire shown above should be connected to a +12 volt supply, and the black wire should be connected to GND of the same supply.

2) If you have to connect using a USB port, you will need Measurand's SAA232-USB cable as shown in Figure E.2. The green 4-pin connector will connect into the four pin terminal block in the SAA232. Make sure that the USB connector is plugged into an available USB port on the computer that will be running the SAARecorder application. The red wire should be connected to a +12 V power supply, and the black wire should be connected to Ground on the same power supply.

3) If you wish to connect to the SAA232 via a serial port on your computer, connect the PC serial port to the green 4-pin connector on the SAA232, using the following wiring:

Pin 1: PC serial port receive (RX)

Pin 2: PC serial port transmit (TX)

Pin 3: +12 V Power

Pin 4: GND (must be connected to both power supply and PC serial port)

4) Go to SAASuite and start SAARecorder. Once the software starts trying to communicate with the SAA, the red LED on the SAA232 should light up.

F. Connecting an SAA to a computer running SAA Suite using an SAA232-5

Multiple SAA can be connected to Measurand's SAA232-5 converter. A picture of the SAA232-5 is shown in Figure F.1 below. The SAA232-5 works in much the same way as the SAA232 (provides surge protection for the SAA and applies power to a single SAA at a time, converts RS232 to RS485) but it can accept up to five SAAs and connects them all to one serial port on the PC. The SAA232-5 is used to sample one SAA at a time through the same PC serial port. For applications where very fast readings are required, multiple SAA232 or SAAUSB devices should be used instead.

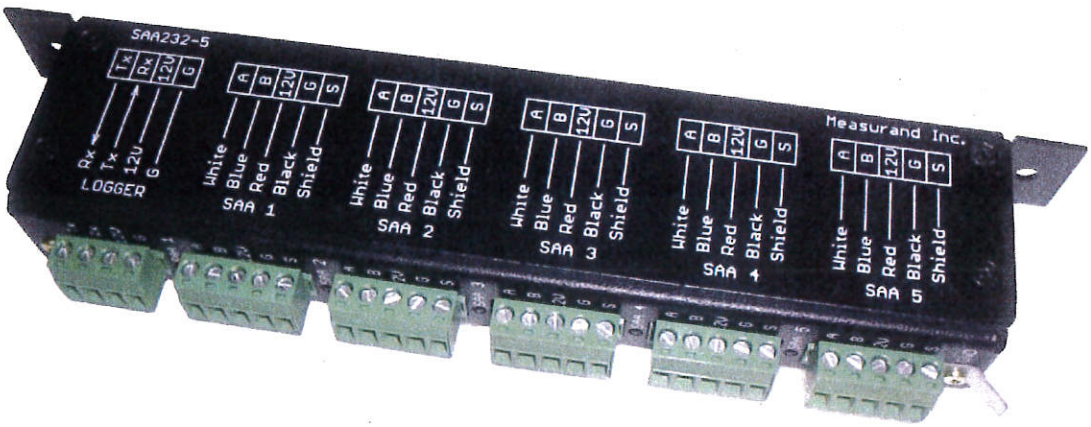

Figure F.1: SAA232-5. 4-pin green connector connects to RS232 port of computer. 5-pin green connectors connect up to five SAAs.

The following steps should be taken when using the SAA232-5 converter with two or more SAA:

1) Connect each SAA to a green 5-pin connector on the SAA232-5 (Figure F.1), making sure to note which SAA is connected to which SAA232-5 port. The SAA wiring is as follows:

Pin 1: White wire (RS485 A)

Pin 2: Blue wire (RS485 B)

Pin 3: Red wire (+12 V to SAA)

Pin 4: Black wire (GND)

Pin 5: Shield

Note: If you are using an older SAA, the wiring may use different colors for the RS485 A and B communications wires, please check with Measurand if you are unsure how to connect these wires.

2) If you have to connect using a USB port, you will need Measurand's SAA232-USB cable as shown in Figure E.E.2. The green 4-pin connector will connect into the four pin terminal block in the SAA232. Make sure that the USB connector is plugged into an available USB port on the computer that will be

running the SAARecorder application. The red wire should be connected to a +12 V power supply, and the black wire should be connected to Ground on the same power supply.

3) If you wish to connect to the SAA232 via a serial port on your computer, connect the PC serial port to the green 4-pin connector on the SAA232, using the following wiring:

Pin 1: PC serial port receive (RX)

Pin 2: PC serial port transmit (TX)

Pin 3: +12 V Power

Pin 4: GND (must be connected to both power supply and PC serial port)

4) Go to SAASuite and start SAARecorder. When the ShapeAccelArray Startup window appears, make sure that the "Using SAA232-5 Device(s)" checkbox is checked (see Figure F.2) then press the "Search For Serial SAAs" button.

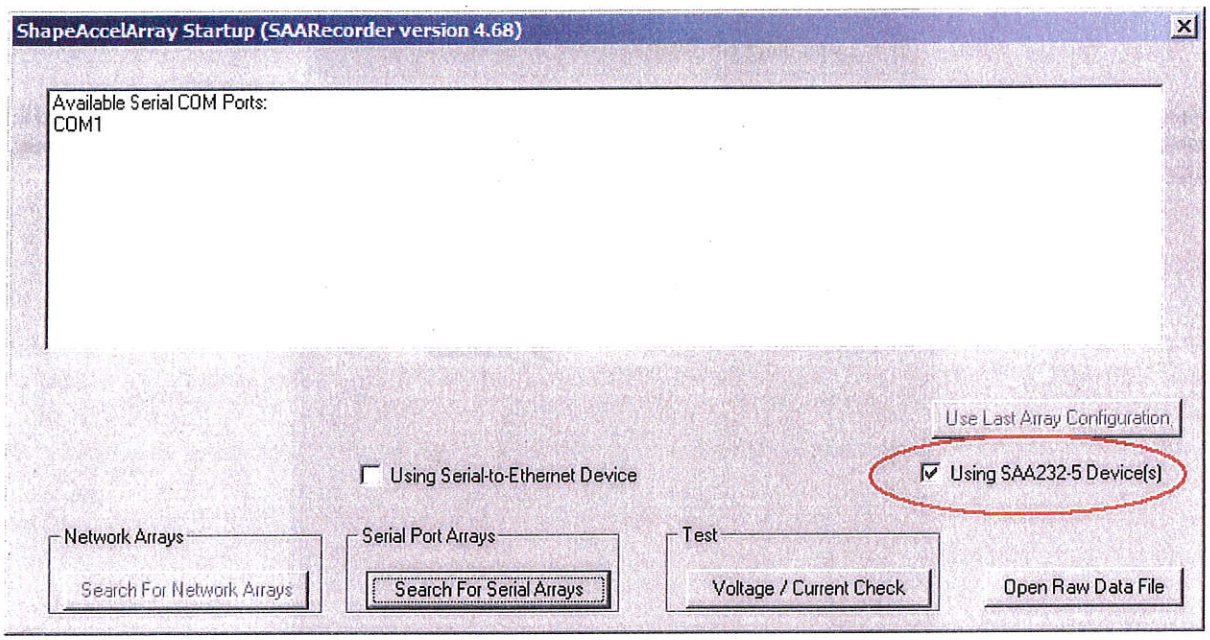

Figure F.2: ShapeAccelArray Startup window with "Using SAA232-5 Device(s)" option checked for use with one or more SAA232-5 devices. Once all SAA are connected to the SAA232-5 device(s), press the "Search For Serial SAAs" button to select serial ports, etc.

Select the COM port(s) being used with the SAA232-5 device(s) and then click OK. Then add the SAA serial numbers to look for in the "Array Serial Numbers to Search" window (Figure F.3) and press the OK button.

An SAA232-5 Port Settings window then appears (Figure F.4), prompting you to choose the serial ports that are connected to the SAA232-5 device(s) and the SAA232-5 port numbers (1 to 5) that are associated with each SAA. Press OK in this window once all selections have been made. SAARecorder will then startup and sample each SAA in turn. The red LED next to each SAA's 5-pin green connector should turn on when that SAA is powered up and being sampled.

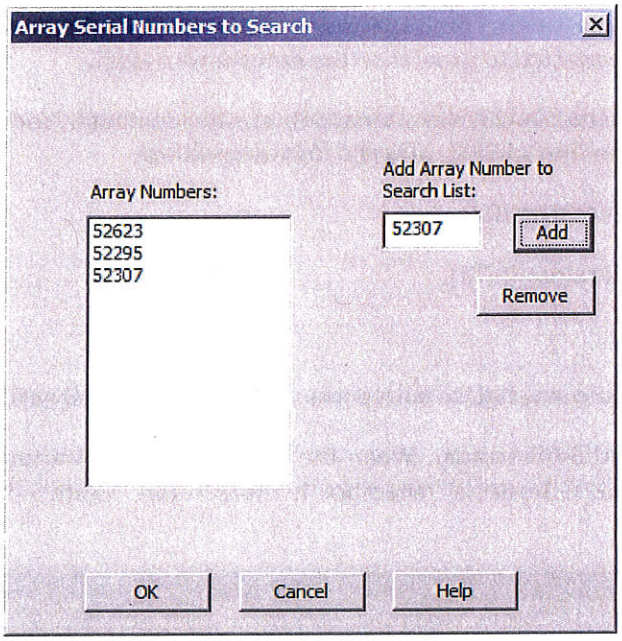

Figure F.3: Arrays Serial Numbers to Search window. If the SAA serial numbers that you will be using are not already listed in the box at left, then type them into the text field at right and press the "Add" button. Once all SAA serial numbers have been listed, press the OK button.

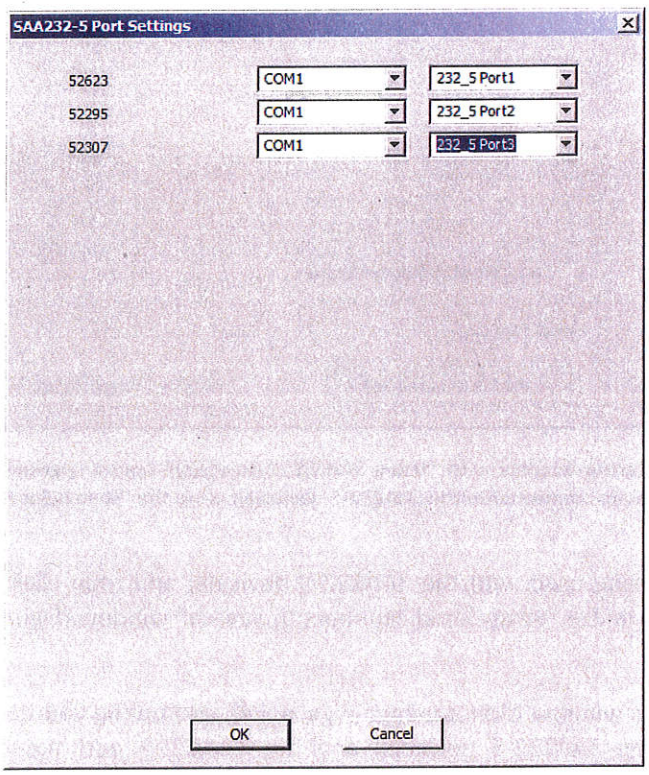

Figure F.4: SAA232-5 Port Settings window. Choose the serial ports that are connected to the SAA232-5 device(s) and the SAA232-5 port numbers (1 to 5) that are associated with each SAA. Press OK in this window once all selections have been made.

G. Connecting an SAA to a computer running SAASuite using the SAAUSB Adapter

Single SAA can be connected using Measurand's SAAUSB adapter shown in Figure G.1 below. The SAAUSB adapter appears as a serial port when it is connected to a computer running SAARecorder.

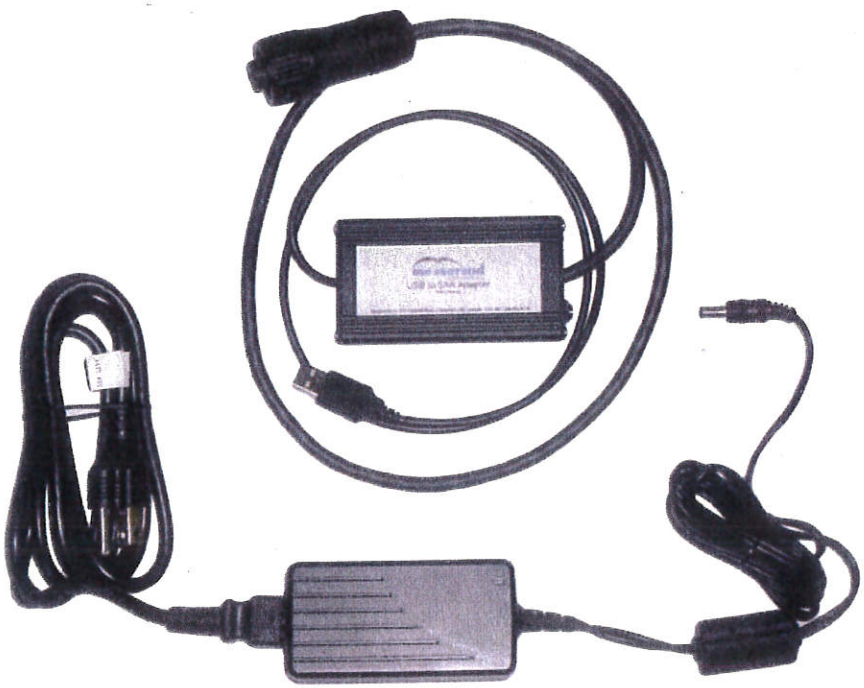

Figure G.1: SAAUSB adapter. This adapter allows the user to interface to a single SAA; it appears as a RS-232 serial port on the PC. The SAA is powered from a +12 volt wall mount supply that plugs directly into the SAAUSB. The USB plug end of the SAAUSB should be plugged into the PC before plugging in the SAA and before finally plugging in the +12 volt power supply.

The following steps should be taken when using the SAAUSB with an SAA:

1) Mate the data cable from the SAA to the round connector of the SAAUSB.

2) Apply power to the SAA by plugging in the +12 VDC power supply into the power injector plug.

3) Plug the USB plug into an available USB port on the PC where SAARecorder is installed.

4) Start the SAARecorder software to collect data.

H. Setting the voltage boost on the SAA232 or SAA232-5

As of September 2012, SAA232 and SAA232-5 contain a component which allows you to boost voltage from the battery up to an output voltage. This allows long SAAs to have longer runs of cable.

In order to adjust the voltage, you need to use a screwdriver to adjust the small screw located on the back of the SAA232 or SAA232-5. Make sure you open the Voltage / Current Check so that you can monitor the voltage at the SAA. Figure H.1 shows the warning that is shown for an SAA with low Voltage. To adjust the voltage, turn the screw until the warning in the Voltage / Current Check disappears.

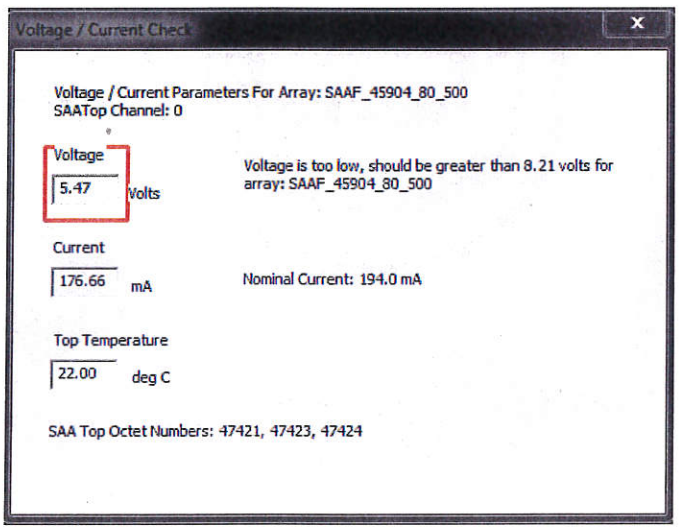

Figure H.1. Low voltage warning

I. Materials Used in SAA Install Kit

The materials provided in the SAA Install Kits are outlined in Tables I.1 and I.2. It is possible to create your own install kit specific to your PVC conduit using the list of materials as a guide. The fittings used in the SAA Install Kits are available at most hardware stores or electrical contractor supply stores.

To create your own top stack with a set screw, you will need to find some set-screws with O-rings. Get a tapping tool with the same thread as the set-screws. Make sure to place the set-screw through the thickest section of the fittings (Figure I.1). Tap the fitting as shown in Figure I.1. To get the O-rings to sit flush against the conduit you will need to flatten the coupling underneath the set-screw using a file.

Table I.1 - SAA Install Kit #1 (with tools)

Quantity	Item Description
1	Pre-assembled top stack
1	3/4" NPT Liquid-Tight Male Straight Connector
20'	3/4" Liquid-Tight nonmetallic Conduit
1	Reducing Bushing, NPT ¾" reduced to ½"
1	Schedule 40 PVC Male Terminal Adapter 1"
1	Schedule 40 PVC Female Adapter 1"
1	Schedule 40 PVC Female Adapter ¾"
3	Schedule 40 PVC Coupling 1"
1	6" long Schedule 40 1" PVC Conduit
1	3" long Schedule 40 1" PVC Conduit
1	Gland ½" NPT
1	18-8 SS Sealing Pan Head ¼"-20
1	1" PVC End Cap
6	large Tie Wraps
1	PVC Quick – Set Cement with MSDS
1	PVC Primer with MSDS
1	Teflon Tape
1	3/4" PEX Tubing Cutter
1	Drill / Tap Bit ¼"-20 NC
1	Multi – Screwdriver
1	1" Pipe Clamp – Hanging Fixture
1	22' cable fishing wire
1	Deburring tool
1	Small flathead screwdriver

Table I.2 - SAA Install Kit #2 (without tools)

Quantity	Item Description
1	Pre-assembled top stack
1	3/4" NPT Liquid-Tight Male Straight Connector
20'	3/4" Liquid-Tight nonmetallic Conduit
1	Reducing Bushing, NPT ¾" reduced to ½"
1	Schedule 40 PVC Male Terminal Adapter 1"
1	Schedule 40 PVC Female Adapter 1"
1	Schedule 40 PVC Female Adapter ¾"
3	Schedule 40 PVC Coupling 1"
1	6" long Schedule 40 1" PVC Conduit
1	3" long Schedule 40 1" PVC Conduit
1	Gland ½" NPT
1	18-8 SS Sealing Pan Head ¼"-20
1	1" PVC End Cap
6	large Tie Wraps
1	1" Pipe Clamp – Hanging Fixture

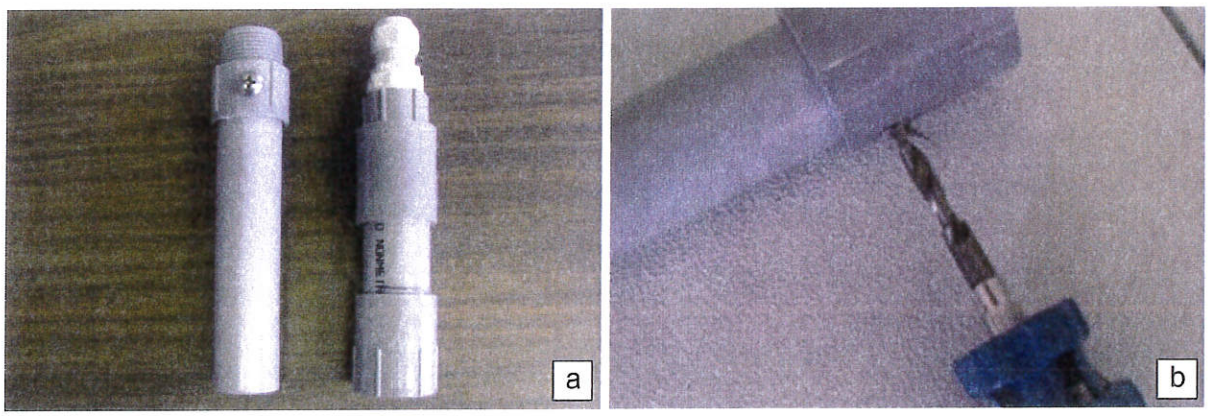

Figure I.1. a) Pre-assembled top stack. b) Tapping the hole for the set-screw in an improvised top stack. Make sure to tap the hole through both the coupling and the conduit to have the strongest connection possible.

J. Sample Calculations for Pipe Ovalization in Horizontal Installations

NOTE: These are sample calculations given as an example of how to determine the pipe size, stiffness, and burial required. This exercise should be done using the appropriate values for the specific site. Minimum acceptable pipe size (after deflection) is 25 mm ID. Maximum deflection allowed is 5% for electrical conduit.

Problem: Want to measure road deflection for a mine haul road using SAA. Can SAA be used and what is the minimum depth of burial.

Truck is a CAT 797F mining truck:

Two axle truck with 2 front tires, 4 back tires. Loaded truck carries 33% weight in front and 67% weight in back

Tire pressure is 600 kPa, but can spike to 900 kPa (131 psi)

Assume same pressure in all tires

Tire footprint: 1.68 m^2

Load per tire = 93 mt

Tire width = 55.1"=1.4 m

Assume surface course for mine road is made crushed rock compacted to >95% of Proctor

E'=3000 psi=20685 kPa

Use Modified Iowa Equation to select pipe. We want the conduit to carry the load so that the instrument is safe. Since this is a large tire load, suggest using Schedule 80. Modified Iowa Equation is given below:

% Deflection= 0.1(LL+DL)100/(0.149(PS)+0.061E')

Where: LL = Live load from tires (psi)

DL = Dead load from soil (psi)

PS = Pipe stiffness (psi)

E' = Modulus of soil reaction (psi)

Option 1: Assume 1.5" Schedule 80 PVC electrical conduit: (from manufacturer specifications)

OD=1.9"=48.3 mm

ID=1.476"=37.5 mm

Pipe stiffness=2911 psi=20070 kPa

Acceptable deflection=5%

Assume SAA conduit is within the surface course (i.e. max depth corresponds with top of base course), and maximum LL is combination of 2 back tires at the top of base course. If conduit is located within 1 m of surface DL is approximately 3 psi:

% Deflection=(0.1 (131×2+3)100)/(0.149(2911)+0.061(3000))=4.3%±1%

Max deflection is 5.3% which is slightly more than 5% recommended for electrical conduit, but ok. Deflection in mm = 2.6 mm, hence does not impact SAA.

Option 2: Assume 1.25" Schedule 80: OD=1.66"=42.2 mm, ID=1.278=32.5 mm, PS=3930 psi=27096 kPa

% Deflection=(0.1 (131×2+3)100)/(0.149(3930)+0.061(3000))=3.4%±1%

Max deflection = 4.4% < 5%, deflection = 1.9 mm, does not impact SAA.

NOTE: These are sample calculations only. Actual calculations are the responsibility of the client.

K. Integrating Other Sensors Into the Main Program (Advanced)

** Please contact Measurand if you need assistance in this procedure. The example given below is not exactly how the code looks today, but it is similar. **

When adding additional sensor programming to the main SAA program, conflicts can arise with existing programming. The SAA_Include references COM Ports 1-4. If any of these ports are used for connecting other sensors, then all references to these ports must be commented out of the serial port subroutines in the SAA_Include file. Provided is an example program for a logger that reads data from vibrating wire piezometers, vibrating wire earth pressure cells, and SAAs.

Note: The SAA-related code in the following example is not the most recent code. This example is meant to give an idea as to how to add other sensors into the 'Main Program'. Please consult Measurand for assistance when trying to combine measurements from various sensors into a single program.

The SAA data is collected over Scan Interval 1 (1 hour) with an AIA averaging level of 1000. The piezometer and earth pressure data is collected at the same interval.

```
'-----------------------------------------------------------------------------------------------------------------------
'Campbell Scientific CR1000 Datalogger Program for collecting ShapeAccelArray (SAA) Data
'Program Author: Jason Bond, Measurand Inc. (built upon single array program by Murray Simpson) (c) 2008

'Version History:
'1.0: Initial internal release
'1.1: 'AVERAGING' added to the PROJECT_INFO file
'1.2: 'PROGRAM_VERSION_NUM' added to the PROJECT_INFO file
    'Program now contains 2 components to prevent editing of critical code by users: i) SAA_Communicator_Vx_x and ii) SAA_Include_Vx_x
'1.3  'Pre-sample added to clear sensor values on first read.
    'ScreenObs subroutine added to filter sensor values.
    'Code added to accomodate partial octets at the end of an SAA
'1.4  'Ability to assign SAAs to any COM port added (instead of requiring sequential use)
    'Ability to use RS232 port to hook up additional SAAs added
'1.5  'SAA now shutdown and repowered after a CRC, COM or range error
    'Check for 0 values added to ScreenObs subroutine
    'Dim u,v As Long variables had to be moved outside of ScreenObs subroutine to compile. Problem arose after updating OS on CR1000.
'1.6   21 Aug 2009:
```

```
    'ScreenObs subroutine removed. Now looked after in SAA3D

    'Range Errors removed from SERIAL_ERRORS_FILE

    'Code to accomdodate partial octets removed. Now looked after in SAA3D.

'1.7  'Various changes made in an attempt to improve computation speed. VERSION NOT RELEASED and changes
not implemented

    'in subsequent versions due to anticipation of new high resolution SAAs. Historical significance only.

    'a)SetSAAPort added to allow switching of SAA baud

    'b)CRC check removed

    'c) Temperature averaging removed - just one value read in SAA data. GetSAASample modified to allow this.

'1.8  A) Addition of alarm notification through email/text:

    'a) input of number of masked segments (from the top)

    'b) input of tilt alarm in degrees

    'c) input of email notification parameters

    'd) addition of storage variable for previous readings


    'B) Addition of high resolution SAA data collection capabilities

    'a) public HIGH_RES_SAA As boolean added

    'b) close, open and flush serial port commands added to shut down sequence when data has failed to be
acquired.


    'Note: When changing the version number, the Include file reference below must be updated and the
VERSION_NUM constant in the include file must be modified

'1.9  Jan. 27, 2010:

    'uses updated include file: CPU:SAA_Include_V1_9.CR1, corrects bug in collection of high res. data from SAA
longer than 8 segments.


    'Note: When changing the version number, the Include file reference below must be updated and the
VERSION_NUM constant in the include file must be modified


'2.3  Uses new include file: CPU:SAA_Include_V2_3.CR1

'2.4  Capable of acquiring voltage, current, and top segment temperature from SAATop devices integrated into the
top of SAA. Uses new include file: CPU:SAA_Include_V2_4.CR1

'2.5  Nov. 12, 2010: Added acquisition of logger voltage and temperature for diagnostic purposes

'2.6  Nov. 29, 2010: Added code for using SAA232_5 device for combining up to 5 SAAs on a single serial port

'2.61  Dec. 7, 2010: Fixed bug in 2.6 for 2nd array data data table

'2.62  Dec. 13, 2010: Modified to sample some preliminary samples as fast as possible upon powerup before
switching to regular scan interval for samples
```

```
'2.63  Mar. 10, 2011: Modified to include array serial numbers in SAA diagnostic files.
'2.64  Aug. 10, 2011: Modified to use new include file: CPU:SAA_Include_V2_63.CR1
'2.65  Aug. 11, 2011: Modified to use new include file: CPU:SAA_Include_V2_64.CR1
'2.66  Aug. 25, 2011: Modified to provide an error table for each array connected to the datalogger.
'2.67  Sept. 27, 2011: Modified to use new include file: CPU::SAA_Include_V2_66.CR1
'2.68  Oct. 7, 2011: Modifieed to use new include file: CPU::SAA_Include_V2_67.CR1, got rid of unused tilt_alarm
stuff
'3.00 Oct. 20, 2011: Simplified, cleaned up code, uses new include file: CPU::SAA_Include_V3_00.CR1.
'3.01 Dec. 5, 2011: Modified to use new include file: CPU::SAA_Include_V3_01.CR1
'3.02 Dec. 12, 2011: Modified to use new include file: CPU::SAA_Include_V3_02.CR1
'3.03 Mar. 05, 2012: Modified to use new include file: CPU::SAA_Include_V3_03.CR1


'DECLARE USER SPECIFIED CONSTANTS (must be modified by user to match application specifications):
'-----------------------------------------------------------------------------------------------------------------------------------
'>>>>>>>>>>>>>>> START <<<<<<<<<<<<<<<
'Enter the number of preliminary samples to capture
Const NUM_PRELIM_SAMPLES = 5
' Enter the number of SAAs to be monitored:

Const NUM_SAAS = 2
' Enter the number of PZ strings to be monitored (has to be at least 1 even if there are no PZ strings !!!)
Const NUMBER_PIEZO_STRINGS = 0
' Enter the number of total devices (number of SAAs + PZ strings):
Const NUM_DEVICES = 2

' Enter the number of Earth Pressure Cells (EPC) to be monitored:
Const NUM_EPCS = 3

' Enter the number of piezometer (PZ) to be monitored:
Const NUM_PZ3S = 12

'>>>>>>>>>>>>>>> START <<<<<<<<<<<<<<<
' Enter the number of raw data samples to average for each measurement:
' Samples can range from 100-25500 if HIGH_RES_SAA = true; samples are collected at 400 Hz, thus ~64 seconds
```

```
are required for NUM_TO_AVG = 25500 (NOTE: HIGH_RES_SAA must be false for older SAAs, sernum < 47100)

' If HIGH_RES_SAA=false, then samples are collected more slowly, and NUM_TO_AVG should be set to between 1 and 100 (typically only used for older SAAs (sernum < 47100).

Const NUM_TO_AVG = 1000

' Enter the maximum number of octets (8 segment units) of any single SAA being used (must be at least 1, even if no SAA octets are present):

Const MAX_NUM_OCTETS = 15

' Enter the maximum number of piezometers per string, must be at least 1, even if no piezometers are used

Const MAX_NUM_PIEZOS = 1

' Enter number of octets for each SAA (each SAA must have an entry):

Const SAA1_NUM_OCTETS = 15

Const SAA2_NUM_OCTETS = 15

' Enter number of piezometers for each Measurand piezometer string (if piezometers are used)

' Const PIEZO1_NUM_PIEZOS = 0

' Enter COM port number for each SAA (each SAA must have an entry) COM1=1, COM2=2, COM3=3, COM4=4

Const SAA1_COM_PORT = 1

Const SAA2_COM_PORT = 2

' Enter COM port number for each Measurand piezometer string (if piezometers are used)

' Const PIEZO1_COM_PORT = 1

' Enter SAA232-5 port number for each SAA (each SAA must have an entry) 1-5 if SAA232-5 port is being used, otherwise enter 0

Const SAA1_232_5_PORT = 0

Const SAA2_232_5_PORT = 0

' Enter SAA232-5 port number for each Measurand piezometer string (if piezometers are used)

'Const PIEZO1_232_5_PORT = 0

' Input whether or not SAATop is present (0 = not present, 1  = SAATop is present) --> typically present in SAAs built in 2011 or later

Const SAA1_SAATOP = 1

Const SAA2_SAATOP = 1

'>>>>>>>>>>>>>>> END <<<<<<<<<<<<<<<

'-----------------------------------------------------------------------------------------------------------------------------------

'END DECLARE USER SPECIFIED CONSTANTS (must be modified by user to match application specifications):

Include "CPU:SAA_Include_V3_03.CR1"



'DECLARE PUBLIC VARIABLES (can be modified by user to match application specifications):
```

```
'-----------------------------------------------------------------------------------------------------------------------------------
'>>>>>>>>>>>>>>> START <<<<<<<<<<<<<<<

'Earth Pressure Cell Public Variables
Public EPC(NUM_EPCS,6)

'Piezometer Public Variables
Public PZ3(NUM_PZ3S,6)

Public Result
Public Power_Save_Flag As Boolean

'add Public ACC, TEMP, and diagnostic variables for each SAA:
'SAA1:
Public SAA1_ACC_VALUES(MAX_NUM_OCTETS,NUM_SENSORS_PER_OCTET) As Float
Public SAA1_TEMP_VALUES(MAX_NUM_OCTETS) As Float
Public SAA1_SAATOP_VOLTAGE As Float
Public SAA1_SAATOP_CURRENT As Float
Public SAA1_SAATOP_TEMPERATURE As Float

'SAA2:
Public SAA2_ACC_VALUES(MAX_NUM_OCTETS,NUM_SENSORS_PER_OCTET) As Float
Public SAA2_TEMP_VALUES(MAX_NUM_OCTETS) As Float
Public SAA2_SAATOP_VOLTAGE As Float
Public SAA2_SAATOP_CURRENT As Float
Public SAA2_SAATOP_TEMPERATURE As Float

'preliminary loop count
Public PRELIM_COUNT As Float

'Data Tables
'Project Descriptor Info

DataTable(PROJECT_INFO,FIRST_SCAN,-1)
        Sample(1,PROGRAM_VERSION_NUM,Float)
```

```
        Sample(1,AVERAGING,Long)
        Sample(1,PROJECT_NAME,String)
        Sample(1,NUMBER_SAAS,Long)
        Sample(NUM_SAAS,NUM_OCTETS_INDEX(),Long)
        Sample(NUM_SAAS*MAX_NUM_OCTETS,SERIAL_NUMS(),Long)
EndTable

'Serial Port Errors:
DataTable(SERIAL_ERRORS,True,-1)
        Sample(1,SERIAL_NUMS(1,1),Long)
        Sample(1,SERIAL_NUMS(2,1),Long)
        Sample(NUM_DEVICES,NUM_CRC_ERRORS,Long)
        Sample(NUM_DEVICES,NUM_COM_ERRORS,Long)
EndTable

'Logger Diagnostics:
DataTable(LOGGER_DIAGNOSTICS,True,-1)
        Sample(1,LOGGER_VOLTAGE,Float)
        Sample(1,LOGGER_TEMPERATURE,Float)
EndTable

'SAA Data Table Values (each SAA requires a data table):
'SAA1:
DataTable(SAA1_DATA,True,-1)
        Sample(1,SERIAL_NUMS(1,1),Long)
        Sample(SAA1_NUM_OCTETS*NUM_SENSORS_PER_OCTET,SAA1_ACC_VALUES(),Float)
        Sample(SAA1_NUM_OCTETS,SAA1_TEMP_VALUES(),Float)
EndTable

'SAA2:
DataTable(SAA2_DATA,True,-1)
        Sample(1,SERIAL_NUMS(2,1),Long)
        Sample(SAA2_NUM_OCTETS*NUM_SENSORS_PER_OCTET,SAA2_ACC_VALUES(),Float)
        Sample(SAA2_NUM_OCTETS,SAA2_TEMP_VALUES(),Float)
EndTable
```

```
DataTable (SAA_DIAGNOSTICS,True,-1)
        Sample(1,SERIAL_NUMS(1,1),Long)
        Sample(1,SERIAL_NUMS(2,1),Long)
        Sample(1,SAA1_SAATOP_VOLTAGE,Float)
        Sample(1,SAA1_SAATOP_CURRENT,Float)
        Sample(1,SAA1_SAATOP_TEMPERATURE,Float)
        Sample(1,SAA2_SAATOP_VOLTAGE,Float)
        Sample(1,SAA2_SAATOP_CURRENT,Float)
        Sample(1,SAA2_SAATOP_TEMPERATURE,Float)
EndTable

' PZ3 Data Table

DataTable(PZ3_DATA, True, -1)
  Sample(NUM_PZ3S*6, PZ3(), IEEE4)
EndTable

' EPC Data Table

DataTable(EPC_DATA, True, -1)
  Sample(NUM_EPCS*6, EPC(), IEEE4)
EndTable

'SUBROUTINES
'-----------------------------------------------------------------------------------------------------------
'*****************************************************************************************************
****************************
'Sub: GetArrayData
'Purpose: gets all of the array data
'Inputs: None
'*****************************************************************************************************
****************************
Sub GetArrayData()
        Scan(1,sec,0,1)'need this dummy scan to auto-allocate data tables
```

```
'fill in project info table:
CallTable PROJECT_INFO
Call GetLoggerDiagnostics()
CallTable LOGGER_DIAGNOSTICS
'add calls to each SAA and store data in respective tables:
'-------------------------------------------------------
'SAA1:
If HIGH_RES_SAA
        Call GetHighResSAAData(SAA1_ACC_VALUES,SAA1_TEMP_VALUES,1)
Else
        Call GetSAAData(SAA1_ACC_VALUES,SAA1_TEMP_VALUES,1)
EndIf
CallTable SAA1_DATA
If SAA1_SAATOP>0
        Call
GetSAATopData(SAA1_SAATOP_VOLTAGE,SAA1_SAATOP_CURRENT,SAA1_SAATOP_TEMPERATURE,1)
EndIf
TurnOffSAA232_5(1)
'SAA2:
If HIGH_RES_SAA
        Call GetHighResSAAData(SAA2_ACC_VALUES,SAA2_TEMP_VALUES,2)
Else
        Call GetSAAData(SAA2_ACC_VALUES,SAA2_TEMP_VALUES,2)
EndIf
CallTable SAA2_DATA
If SAA2_SAATOP>0
        Call
GetSAATopData(SAA2_SAATOP_VOLTAGE,SAA2_SAATOP_CURRENT,SAA2_SAATOP_TEMPERATURE,2)
EndIf
TurnOffSAA232_5(2)
CallTable SAA_DIAGNOSTICS


'record serial errors table:
CallTable SERIAL_ERRORS
```

```
        'turn off outputting of project descriptor info after first run:
        FIRST_SCAN = false
        NextScan
EndSub

Sub GetVWData()

  Scan(1,sec,0,1)'need this dummy scan to auto-allocate data tables
    'Get Piezometer Data
    SerialOpen (COM4,38400,4,0,0)
    AVW200 (Result(),COM4,0,200,PZ3(1,1),1,1,NUM_PZ3S,1400,3500,1,_60Hz,1,0)

    CallTable PZ3_DATA

    AVW200 (Result(),COM4,0,200,EPC(1,1),1,13,NUM_EPCS,1400,3500,1,_60Hz,1,0)

    CallTable EPC_DATA

    SerialClose(COM4)
  NextScan

EndSub



'DEFINE MAIN PROGRAM:
'-----------------------------------------------------------------------------------------------------------------------------------

BeginProg
        'setup project descriptors:
        '--------------------------
        '>>>>>>>>>>>>>>>> START <<<<<<<<<<<<<<<<
        ' Enter the Project Title
        PROJECT_NAME = "Integration Example"
        '>>>>>>>>>>>>>>>>  END  <<<<<<<<<<<<<<<<
```

```
NUMBER_SAAS = NUM_SAAS
AVERAGING = NUM_TO_AVG
PROGRAM_VERSION_NUM = VERSION_NUM
HIGH_RES_SAA = true

'declare the serial numbers (each octet) for each SAA:
'---------------------------------------
'SAA1 - S/N: 50013 nodes 50013 50019 50070 50083 50206 50225 50315 50347 50402 50413 50416 50438 50451 50515 51358
SERIAL_NUMS(1,1) = 50013
SERIAL_NUMS(1,2) = 50019
SERIAL_NUMS(1,3) = 50070
SERIAL_NUMS(1,4) = 50083
SERIAL_NUMS(1,5) = 50206
SERIAL_NUMS(1,6) = 50225
SERIAL_NUMS(1,7) = 50315
SERIAL_NUMS(1,8) = 50347
SERIAL_NUMS(1,9) = 50402
SERIAL_NUMS(1,10) = 50413
SERIAL_NUMS(1,11) = 50416
SERIAL_NUMS(1,12) = 50438
SERIAL_NUMS(1,13) = 50451
SERIAL_NUMS(1,14) = 50515
SERIAL_NUMS(1,15) = 51358

'SAA2 - S/N: 50021 nodes 50021 50226 50246 50440 50550 50557 50563 50565 50570 50968 50969 50982 50996 50998 50039
SERIAL_NUMS(2,1) = 50021
SERIAL_NUMS(2,2) = 50226
SERIAL_NUMS(2,3) = 50246
SERIAL_NUMS(2,4) = 50440
SERIAL_NUMS(2,5) = 50550
SERIAL_NUMS(2,6) = 50557
SERIAL_NUMS(2,7) = 50563
SERIAL_NUMS(2,8) = 50565
```

```
SERIAL_NUMS(2,9) = 50570
SERIAL_NUMS(2,10) = 50968
SERIAL_NUMS(2,11) = 50969
SERIAL_NUMS(2,12) = 50982
SERIAL_NUMS(2,13) = 50996
SERIAL_NUMS(2,14) = 50998
SERIAL_NUMS(2,15) = 50039

'declare the number of octets for each SAA:
'-----------------------------------------

'SAA 1:
NUM_OCTETS_INDEX(1) = SAA1_NUM_OCTETS
'SAA 2:
NUM_OCTETS_INDEX(2) = SAA2_NUM_OCTETS

'declare the com port assignment for each SAA:
'-----------------------------------------

'SAA1:
COM_PORT(1) = SAA1_COM_PORT
SAA232_5_PORT_INDEX(1) = SAA1_232_5_PORT

'SAA2:
COM_PORT(2) = SAA2_COM_PORT
SAA232_5_PORT_INDEX(2) = SAA2_232_5_PORT

'initialize COM and CRC errors:
NUM_COM_ERRORS = 0
NUM_CRC_ERRORS = 0

'initialize SAATOP parameters
SAA1_SAATOP_VOLTAGE=0.0
SAA1_SAATOP_CURRENT=0.0
SAA1_SAATOP_TEMPERATURE=0.0
```

```
        SAA2_SAATOP_VOLTAGE=0.0
        SAA2_SAATOP_CURRENT=0.0
        SAA2_SAATOP_TEMPERATURE=0.0

        'declare the SAATop channel of each SAA:
        '-----------------------------------
        'SAA1:
        SAATOP_CHANNEL_INDEX(1) = 0
        'SAA2:
        SAATOP_CHANNEL_INDEX(2) = 0

 'initialize power saving flag
 Power_Save_Flag = True

 'make sure modem starts off being on
 SW12(1)

 FIRST_SCAN = true
 'do preliminary scans first
 For PRELIM_COUNT=1 To NUM_PRELIM_SAMPLES
          Call GetVWData()
   Call GetArrayData()
          Delay(0,10,2)
 Next PRELIM_COUNT

'now do actual scan indefinitely
'>>>>>>>>>>>>>>> START <<<<<<<<<<<<<<<
Scan (1,hr,0,0)
'>>>>>>>>>>>>>>>  END  <<<<<<<<<<<<<<<

  'power switching

  If Power_Save_Flag = True Then
```

```
    If TimeIntoInterval(0,24,Hr) Then
      SW12(0)
    EndIf

    If TimeIntoInterval(6,24,Hr) Then
      SW12(1)
    EndIf

  Else
    SW12(1)
  EndIf

  ' get VW sensor data

  Call GetVWData()

  ' get SAA data

        Call GetArrayData()
NextScan
EndProg
```

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WHEN MEASUREMENTS MATTER

CR800-Series

Measurement & Control Systems

Rugged

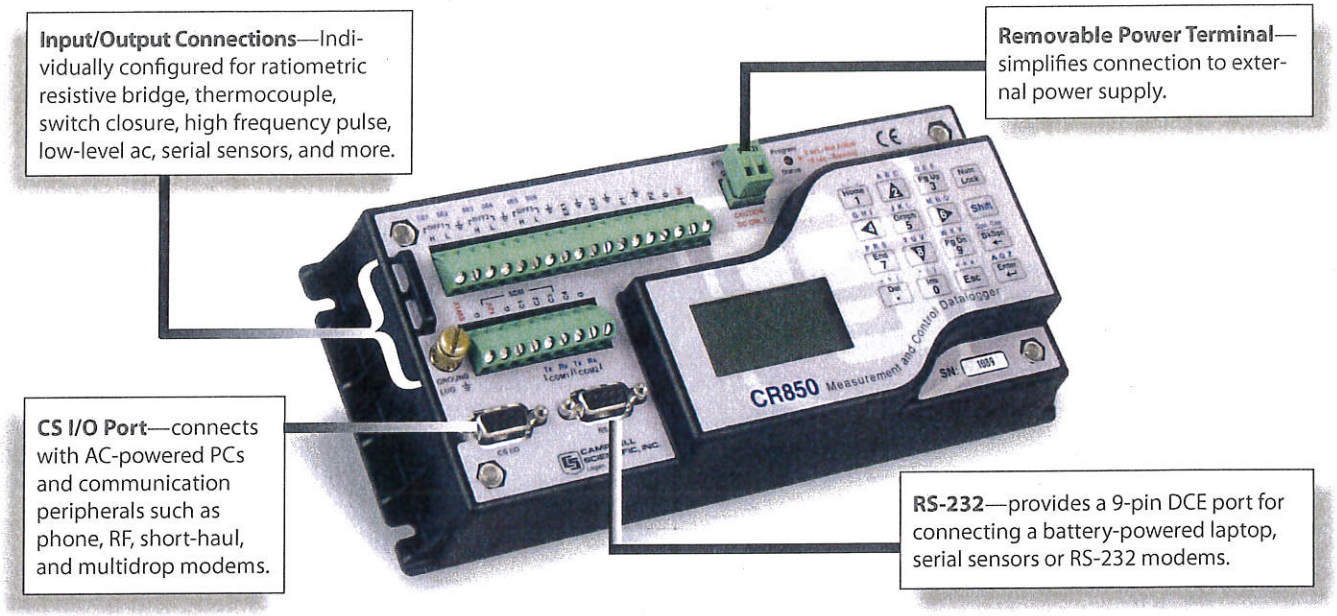
Instruments with

Research-Grade

Performance

CR800 & CR850 Measurement and Control Systems

The CR800 and CR850 dataloggers provide precision measurement capabilities in a rugged, battery-operated package. Both models consist of measurement electronics encased in a plastic shell and an integrated wiring panel. The standard operating range is -25° to +50°C. An extended range of -55° to +85°C for the CR800 or -30°to +80°C for the CR850 is also available.



Features

- 4 MB* of battery-backed SRAM
- Program execution rate of up to 100 Hz
- CS I/O and RS-232 serial ports
- 13-bit analog to digital conversions
- 16-bit microcontroller with 32-bit internal CPU architecture
- Temperature compensated real-time clock
- Background system calibration for accurate measurements over time and temperature changes
- Single DAC used for excitation and measurements to give ratiometric measurements
- Gas Discharge Tube (GDT) protected inputs
- Data values stored in tables with a time stamp and record number
- Battery-backed SRAM and clock that ensure data, programs, and accurate time are maintained while a CR800-series datalogger is disconnected from the main power source
- One program-status LED
- Serial communications with serial sensors and devices supported via I/O port pairs
- PakBus, Modbus, and DNP3 protocols supported

Model Descriptions

The models differ in their keyboard display. The CR800 uses an external keyboard display, the CR1000KD, which connects to the CR800 via its CS I/O port. The CR850 includes an on-board keyboard display as part of its integrated package.

Operating System/Logic Control

The on-board operating system includes measurement, processing, and output instructions for programming the datalogger. The programming language, CRBasic, uses a BASIC-like syntax. Measurement instructions specific to bridge configurations, voltage outputs, thermocouples, and pulse/frequency signals are included. Processing instructions support algebraic, statistical, and transcendental functions for on-site processing. Output instructions process data over time and control external devices.

Storage Capacity*

The CR800 series has 2 MB of flash memory for the Operating System, and 4 MB of battery-backed SRAM for CPU usage, program storage, and data storage. Data is stored in a table format.

**Campbell Scientific is increasing the data storage memory from 2 MB to 4 MB. Dataloggers with a serial number greater than or equal to 3605 will have a 4 MB memory. The 4 MB dataloggers will also have a sticker on the canister stating "4M Memory".*

Input Output Terminals

Analog Inputs
Three differential (6 single-ended) channels measure voltage levels. Resolution on the most sensitive range is 0.67 μV.

Pulse Counters
The CR800 and CR850 have two pulse channels that can count pulses from high level (5 V square wave), switch closure, or low level AC signals.

Switched Voltage Excitations
Two outputs provide precision excitation voltages for resistive bridge measurements.

Digital I/O Ports
The CR800-series dataloggers include four ports for frequency measurements, digital control, and triggering. Three of these ports can also be used to measure SDM devices. The I/O ports can be paired as transmit and receive. Each pair has 0 to 5 V UART hardware that allows serial communications with serial sensors and devices. An RS-232-to-logic level converter may be required in some cases.

CS I/O Port
AC-powered PCs and many communication peripherals connect with the datalogger via this port. Connection to an AC-powered PC requires either an SC32B or SC-USB interface. These interfaces isolate the PC's electrical system from the datalogger, thereby protecting against ground loops, normal static discharge, and noise.

RS-232 Port
This non-isolated port is for connecting a battery-powered laptop, serial sensor, or RS-232 modem. Because of ground loop potential on some measurements (e.g., low level single-ended), AC-powered PCs should use the CS I/O port instead of the RS-232 port (see above).

Switched 12 Volt
This terminal provides unregulated 12 V that can be switched on and off under program control.

Enclosure/Stack Bracket

A CR800 or CR850 housed in a weather-resistant enclosure can collect data under extremely harsh conditions. The 28960 Enclosure Stack Mounting Kit allows a small peripheral to be placed under the mounting bracket, thus conserving space.

Communication Protocols

The CR800 series supports the PakBus, Modbus, DNP3,TCP/IP, FTP, and SMTP communication protocols. With the PakBus protocol, networks have the distributed routing intelligence to continually evaluate links. Continually evaluating links optimizes delivery times and, in the case of delivery failure, allows automatic switch over to a configured backup route.

The Modbus RTU protocol supports both floating point and long formats. The datalogger can act as a slave and/or master.

The DNP3 protocol supports only long data formats. The dataloggers are level 2 slave compliant, with some of the operations found in a level 3 implementation.

The TCP/IP, FTP, and SMTP protocols provide TCP/IP functionality when the datalogger is used in conjunction with an NL200 or NL240.

Transient Protection

Gas Discharge Tube (GDT) protects the inputs from electrical transients. The CR800 series is CE compliant under the European Union's EMC Directive, meeting ESD, EMC, Fast Transient standards.

Power Supplies

Typically, the CR800-series dataloggers are powered with a PS200, PS100, or BPALK. The PS200 and PS100 provide a 7-Ah sealed rechargeable battery that should be connected to a charging source (either a wall charger or solar panel). The BPALK consists of eight non-rechargeable D-cell alkaline batteries with a 7.5-Ah rating at 20°C.

Also available are the BP12 and BP24 battery packs, which provide nominal ratings of 12 and 24 Ah, respectively. These batteries should be connected to a regulated charging source (e.g., a CH200 or CH100 connected to a unregulated solar panel or wall charger).

The PS200 and CH200 (at right) are micro-controller-based smart chargers that have two input terminals that allow simultaneous connection of two charging sources.

Communication Options

To determine the best option for an application, consider the accessibility of the site, availability of services (e.g., cellular phone or satellite coverage), quantity of data to collect, and desired time between data-collection sessions. Some communication options can be combined—increasing the flexibility, convenience, and reliability of the communications.

External Data Storage Device
The CR800 and CR850 can use the SC115 2-GB Flash Memory Drive to augment onsite data storage or to transport data between the datalogger and PC.

The SC115 is a light-weight, portable instrument that fits in a pocket allowing easy transport between the datalogger and PC.

Keyboard Display
Keyboard displays are used to program the datalogger, manually initiate data transfer, and display data. Both the CR850's integrated keyboard display and the CR1000KD can show 8 lines x 21 characters (64 x 128 pixels). Their keyboard includes 16 characters. Custom menus are supported allowing customers to set up choices within the datalogger program that can be initiated by a simple "toggle" or "pick list".

Mountable Displays
The CD100 and CD295 can be mounted in an enclosure lid. The CD100 has the same functionality and operation as the CD1000KD, allowing both data entry and display without opening the enclosure. The CD295 displays real-time data only.

iOS Devices, Android Devices, and PDAs
An iOS device, an Android device, our Archer-PCON Field PC, or a user-supplied PDA can be used to view and collect data, set the clock, and download programs. To use an iOS or Android device, go to the Apple Store or Google Play and purchase our LoggerLink Mobile Apps. User-supplied PDAs require either PConnect or PConnectCE software.

Direct Links
AC-powered PCs connect with the datalogger's CS I/O port via an SC32B or SC-USB interface. These interfaces provide optical isolation. A battery-powered laptop can be attached to the datalogger's RS-232 port via an RS-232 cable; no interface required.

Internet and IP Networks
The NL240, NL200, or NL100 interfaces enable the CR800-series datalogger to communicate with a PC via TCP/IP.

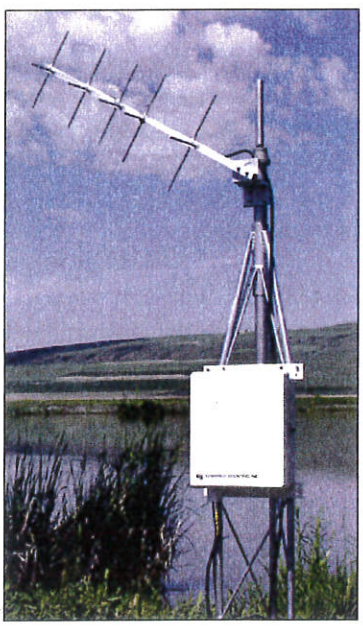
Multidrop Interface
The MD485 intelligent RS-485 interface permits a PC to address and communicate with one or more dataloggers over the CABLE2TP two-twisted pair cable. Distances up to 4000 feet are supported.

Radios
Radio frequency (RF) communications are supported via narrow-band UHF, narrow-band VHF, spread spectrum, or meteor burst radios. Line-of-sight is required for all of our RF options.

Telephone Networks
The CR800 series can communicate with a PC using landlines, cellular CDMA, or cellular GPRS transceivers. A voice synthesized modem enables anyone to call the datalogger via phone and receive a verbal report of real-time site conditions.

Short Haul Modems
The SRM-5A RAD Short Haul Modem supports communications between the datalogger and a PC via a four-wire unconditioned line (two twisted pairs).

Satellite Transmitters
Our NESDIS-certified GOES satellite transmitter provides one-way communications from a Data Collection Platform (DCP) to a receiving station. We also offer an Argos transmitter that is ideal for high-latitude applications.



Our GOES transmitters are used for stream stage (shown), water quality, and rainfall applications.

Channel Expansion

4-Channel Low Level AC Module

The LLAC4 is a small peripheral device that allows customers to increase the number of available low-level AC inputs by using control ports. This module is often used to measure up to four anemometers, and is especially useful for wind profiling applications.

Multiplexers

Multiplexers increase the number of sensors that can be measured by a datalogger by sequentially connecting each sensor to the datalogger. Several multiplexers can be controlled by a single datalogger. The CR800 and CR850 are compatible with the AM16/32B and AM25T multiplexers.

Synchronous Devices for Measurement (SDMs)

SDMs are addressable peripherals that expand the datalogger's measurement and control capabilities. For example, SDMs are available to add control ports, analog outputs, pulse count channels, interval timers, or even a CANbus interface to the system. Multiple SDMs, in any combination, can be connected to one datalogger.

The SDM-SIO1 Serial Input/Output Module is fully compliant with the RS-232 standards. It allows a CR800 or CR850 to communicate with up to 17 serial devices.

Software

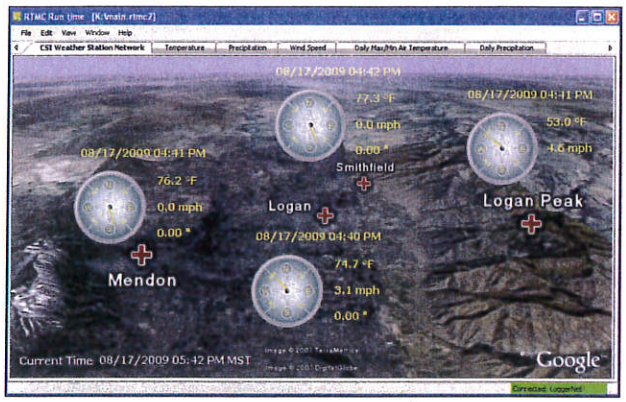
Starter Software

Our easy-to-use starter software is intended for first time users or applications that don't require sophisticated communications or datalogger program editing. SCWin Short Cut generates straight-forward datalogger programs in four easy steps. PC200W allows customers to transfer a program to, or retrieve data from a CR800 or CR850 via a direct communications link.

At www.campbellsci.com/downloads, the starter software can be downloaded at no charge. Our Resource CD also provides this software as well as PDF versions of our brochures and manuals.

Datalogger Support Software

Our datalogger support software packages provide more capabilities than our starter software. These software packages contains program editing, communications, and display tools that can support an entire datalogger network.

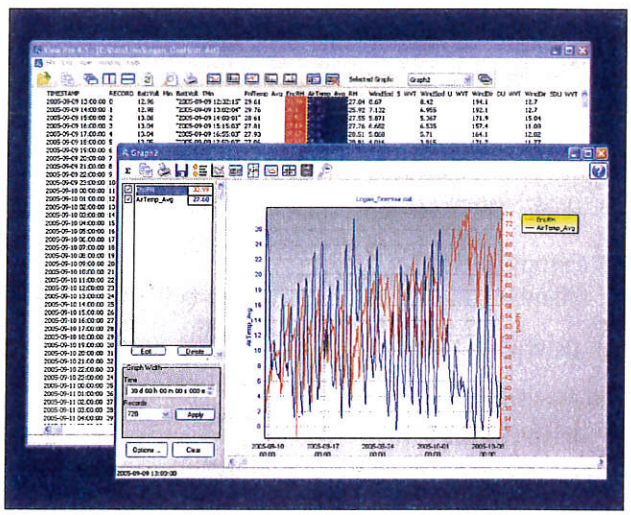


RTMC, a program for displaying the datalogger's data, is bundled with LoggerNet and RTDAQ. Customers may also purchase the RTMCRT and RTMC Web Server clients, which use forms created in the developer mode of RTMC.

PC400, our mid-level software, supports a variety of telemetry options, manual data collection, and data display. For programming, it includes both Short Cut and the CRBasic program editor. PC400 does not support combined communication options (e.g., phone-to-RF), PakBus® routing, and scheduled data collection.

RTDAQ is an ideal solution for industrial and real-time users desiring to use reliable data collection software over a single telecommunications medium, and who do not rely on scheduled data collection. RTDAQ's strength lies in its ability to handle the display of high speed data.

LoggerNet is Campbell Scientific's full-featured datalogger support software. It is referred to as "full-featured" because it provides a way to accomplish almost all the tasks you'll need to complete when using a datalogger. LoggerNet supports combined communication options (e.g., phone-to-RF) and scheduled data collection.



Both LoggerNet and RTDAQ use View Pro to display historical data in a tabular or graphical format.

Applications

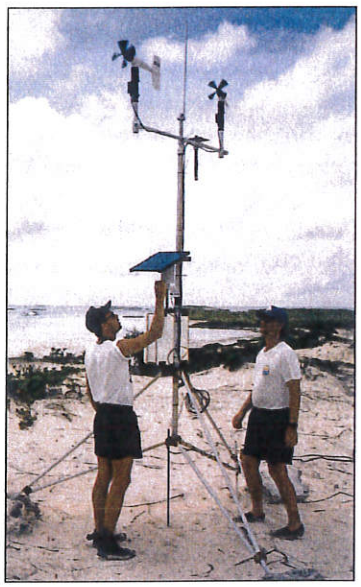
The measurement precision, flexibility, long-term reliability, and economical price of the CR800 and CR850 make them ideal for scientific, commercial, and industrial applications.

Meteorology

The CR800 series is used in long-term climatological monitoring, meteorological research, and routine weather measurement applications.

Sensors the CR800 series can measure include:

- cup, propeller, and sonic anemometers
- tipping bucket rain gages
- wind vanes
- pyranometers
- ultrasonic ranging sensor
- thermistors, RTDs, and thermocouples
- barometers
- RH probes



Meteorological conditions affecting marine larvae distribution are monitored at Exuma Cay, Bahamas.

Data is output in a choice of units (e.g., wind speed in miles per hour, meters per second, or knots). Standard outputs include wind vector averaging, sigma, theta, and histograms.

Agriculture and Agricultural Research

The versatility of the CR800 and CR850 allows measurement of agricultural processes and equipment in applications such as:

- plant water research
- canopy energy balance
- plant pathology
- machinery performance
- frost prediction
- crop management decisions
- food processing/ storage
- integrated pest management
- irrigation scheduling

Wind Profiling

Our data acquisition systems can monitor conditions at wind assessment sites, at producing wind farms, and along transmission lines. The reliability of these systems ensures data collection, even under adverse conditions. Wide operating temperature ranges and weatherproof enclosures allow our systems to operate reliably in harsh environments.

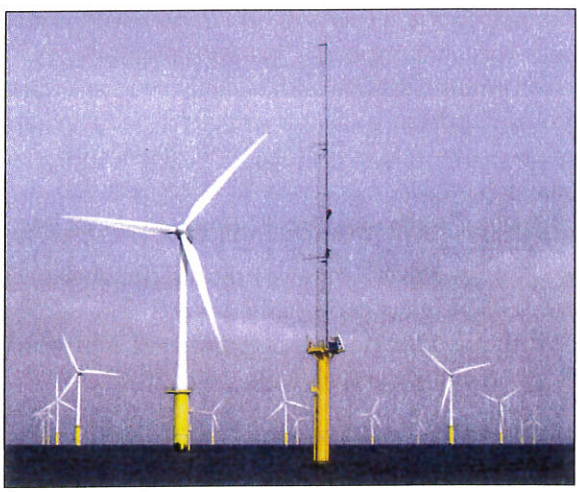
The CR800 or CR850 makes and records measurements, controls electrical devices, and can function as PLCs or RTUs. Because the datalogger has its own power supply (batteries, solar panels), it can continue to measure and store data and perform control during power outages.

Typical sensors for wind assessment applications include, but are not limited to:

- cup, propeller, and sonic anemometers (up to 10 anemometers can be measured by using two LLAC4 peripherals)
- wind vanes
- thermistors, RTDs, and thermocouples
- barometers
- pyranometers

For turbine performance applications, the CR800 series monitors electrical current, voltage, wattage, stress, and torque.

Photo courtesy RADTech Ltd. UK



A Campbell Scientific datalogging system monitors this offshore wind farm located between Rhyl and Prestatyn in North Wales at about 7 to 8 km out to sea.

Air Quality

The CR800 series can monitor and control gas analyzers, particle samplers, and visibility sensors. The datalogger can also automatically control calibration sequences and compute conditional averages that exclude invalid data (e.g., data recorded during power failures or calibration intervals).

Water Resources/Aquaculture

Our CR800 series is well-suited to remote, unattended monitoring of hydrologic conditions. Most hydrologic sensors, including SDI-12 probes, interface directly to the datalogger.

The CR800-series dataloggers are ideal for monitoring water quality and level at reservoirs, springs, canals, pipelines, and culinary sites.

Typical hydrologic measurements:

- **Water level** is monitored with incremental shaft encoders, double bubblers, ultrasonic ranging sensors, resistance tapes, strain gage pressure transducers, or vibrating wire pressure transducers. Vibrating wire transducers require an AVW200 series or another Vibrating Wire Interface.
- **Well draw-down tests** use a pressure transducer measured at logarithmic intervals or at a rate based on incremental changes in water level.
- **Ionic conductivity measurements** use one of the switched excitation ports from the datalogger.
- **Samplers** are controlled by the CR800 or CR850 as a function of time, water quality, or water level.
- **Alarm and pump actuation** are controlled through digital I/O ports that operate external relay drivers.

Vehicle Testing

This versatile, rugged datalogger is ideally suited for testing cold and hot temperature, high altitude, off-highway, and cross-country performance. The CR800 and CR850 are compatible with our SDM-CAN interface, GPS16X-HVS receiver.

Vehicle monitoring includes not only passenger cars, but airplanes, locomotives, helicopters, tractors, buses, heavy trucks, drilling rigs, race cars, and motorcycles.

Soil Moisture

The CR800 and CR850 are compatible with the following soil moisture measurement technologies:

- Soil moisture blocks are inexpensive sensors that estimate soil water potential.
- Matric water potential sensors also estimate soil water potential but are more durable than soil moisture blocks.
- Time-Domain Reflectometry Systems (TDR) use a reflectometer controlled by the datalogger to accurately measure soil water content. Multiplexers allow sequential measurement of a large number of probes by one reflectometer.
- Self-contained water content reflectometers are sensors that emit and measure a TDR pulse.
- Tensiometers measure the soil pore pressure of irrigated soils and calculate soil moisture.

Other Applications

- Wireless sensor/ datalogger networks
- Avalanche forecasting, snow science, polar, high altitude
- Fire weather
- Geotechnical
- Historic preservation

Data measured by this weather station near Aspen, Colorado is used in avalanche forecasting.

CR800-Series Specifications

Electrical specifications are valid over a -25° to +50°C, non-condensing environment, unless otherwise specified. Recalibration recommended every two years. Critical specifications and system configuration should be confirmed with Campbell Scientific before purchase.

PROGRAM EXECUTION RATE

10 ms to one day @ 10 ms increments

ANALOG INPUTS (SE1-SE6 or DIFF1-DIFF3)

3 differential (DF) or 6 single-ended (SE) individually configured input channels. Channel expansion provided by optional multiplexers.

RANGES and RESOLUTION: Basic resolution (Basic Res) is the A/D resolution of a single conversion. Resolution of DF measurements with input reversal is half the Basic Res.

Range (mV)[1]	DF Res (µV)[2]	Basic Res (µV)
±5000	667	1333
±2500	333	667
±250	33.3	66.7
±25	3.33	6.7
±7.5	1.0	2.0
±2.5	0.33	0.67

[1]Range overhead of ~9% on all ranges guarantees that full-scale values will not cause over range.

[2]Resolution of DF measurements with input reversal.

ACCURACY[3]:
±(0.06% of reading + offset), 0° to 40°C
±(0.12% of reading + offset), -25° to 50°C
±(0.18% of reading + offset), -55° to 85°C (-XT only)

[3]Accuracy does not include sensor and measurement noise. Offsets are defined as:

Offset for DF w/input reversal = 1.5·Basic Res + 1.0 µV
Offset for DF w/o input reversal = 3·Basic Res + 2.0 µV
Offset for SE = 3·Basic Res + 3.0 µV

ANALOG MEASUREMENT SPEED:

Integration Type/ Code	Integration Time	Settling Time	Total Time[5] SE w/ No Rev	Total Time[5] DF w/ Input Rev
250	250 µs	450 µs	~1 ms	~12 ms
60 Hz[4]	16.67 ms	3 ms	~20 ms	~40 ms
50 Hz[4]	20.00 ms	3 ms	~25 ms	~50 ms

[4]AC line noise filter.

[5]Includes 250 µs for conversion to engineering units.

INPUT NOISE VOLTAGE: For DF measurements with input reversal on ±2.5 mV input range; digital resolution dominates for higher ranges.
250 µs Integration: 0.34 µV RMS
50/60 Hz Integration: 0.19 µV RMS

INPUT LIMITS: ±5 V

DC COMMON MODE REJECTION: >100 dB

NORMAL MODE REJECTION: 70 dB @ 60 Hz when using 60 Hz rejection

SUSTAINED INPUT VOLTAGE W/O DAMAGE: ±16 Vdc max.

INPUT CURRENT: ±1 nA typical, ±6 nA max. @ 50°C; ±90 nA @ 85°C

INPUT RESISTANCE: 20 Gohms typical

ACCURACY OF BUILT-IN REFERENCE JUNCTION THERMISTOR (for thermocouple measurements):
±0.3°C, -25° to 50°C
±0.8°C, -55° to 85°C (-XT only)

ANALOG OUTPUTS (Vx1-Vx2)

2 switched voltage, active only during measurement, one at a time.

RANGE AND RESOLUTION: Voltage outputs programmable between ±2.5 V with 0.67 mV resolution.

V_x ACCURACY: ±(0.06% of setting + 0.8 mV), 0° to 40°C
±(0.12% of setting + 0.8 mV), -25° to 50°C
±(0.18% of setting + 0.8 mV), -55° to 85°C (-XT only)

V_x FREQUENCY SWEEP FUNCTION: Switched outputs provide a programmable swept frequency, 0 to 2500 mv square waves for exciting vibrating wire transducers.

CURRENT SOURCING/SINKING: ±25 mA

RESISTANCE MEASUREMENTS

MEASUREMENT TYPES: Ratiometric measurements of 4- and 6-wire full bridges, and 2-, 3-, and 4-wire half bridges. Precise, dual polarity excitation for voltage excitation eliminates dc errors. Offset values are reduced by a factor of 2 when excitation reversal is used.

VOLTAGE RATIO ACCURACY[6]: Assuming excitation voltage of at least 1000 mV, not including bridge resistor error.

±(0.04% of voltage reading + offset)/V_x

[6]Accuracy does not include sensor and measurement noise. Offsets are defined as:

Offset for DF w/input reversal = 1.5·Basic Res + 1.0 µV
Offset for DF w/o input reversal = 3·Basic Res + 2.0 µV
Offset for SE = 3·Basic Res + 3.0 µV

PERIOD AVERAGING MEASUREMENTS

Any of the 6 SE analog inputs can be used for period averaging. Accuracy is ±(0.01% of reading + resolution), where resolution is 136 ns divided by the specified number of cycles to be measured.

INPUT AMPLITUDE AND FREQUENCY:

Voltage Gain	Input Range (±mV)	Signal (peak to peak)[7] Min. (mV)	Signal (peak to peak)[7] Max (V)	Min Pulse Width (µV)	Max[8] Freq (kHz)
1	250	500	10	2.5	200
10	25	10	2	10	50
33	7.5	5	2	62	8
100	2.5	2	2	100	5

[7]With signal centered at the datalogger ground.

[8]The maximum frequency = 1/(Twice Minimum Pulse Width) for 50% of duty cycle signals.

PULSE COUNTERS (P1-P2)

2 inputs individually selectable for switch closure, high frequency pulse, or low-level ac. Independent 24-bit counters for each input.

MAXIMUM COUNTS PER SCAN: 16.7 x 10^6

SWITCH CLOSURE MODE:
Minimum Switch Closed Time: 5 ms
Minimum Switch Open Time: 6 ms
Max. Bounce Time: 1 ms open w/o being counted

HIGH FREQUENCY PULSE MODE:
Maximum Input Frequency: 250 kHz
Maximum Input Voltage: ±20 V
Voltage Thresholds: Count upon transition from below 0.9 V to above 2.2 V after input filter with 1.2 µs time constant.

LOW LEVEL AC MODE: Internal ac coupling removes dc offsets up to ±0.5 V.

Input Hysteresis: 12 mV @ 1 Hz
Maximum ac Input Voltage: ±20 V
Minimum ac Input Voltage:

Sine Wave (mV RMS)	Range(Hz)
20	1.0 to 20
200	0.5 to 200
2000	0.3 to 10,000
5000	0.3 to 20,000

DIGITAL I/O PORTS (C1-C4)

4 ports software selectable, as binary inputs or control outputs. Provide edge timing, subroutine interrupts/ wake up, switch closure pulse counting, high frequency pulse counting, asynchronous communications (UARTs), SDI-12 communications, and SDM communications.

HIGH FREQUENCY MAX: 400 kHz

SWITCH CLOSURE FREQUENCY MAX: 150 Hz

EDGE TIMING RESOLUTION: 540 ns

OUTPUT VOLTAGES (no load): high 5.0 V ±0.1 V; low <0.1

OUTPUT RESISTANCE: 330 ohms

INPUT STATE: high 3.8 to 16 V; low -8.0 to 1.2 V

INPUT HYSTERISIS: 1.4 V

INPUT RESISTANCE: 100 kohm with inputs <6.2 Vdc
220 ohms with inputs ≥6.2 Vdc

SWITCHED 12 V (SW12)

One independent 12 Vdc unregulated source is switched on and off under program control. Thermal fuse hold current = 900 mA @ 20°C, 650 mA @ 50°C, 360 mA @ 85°C.

CE COMPLIANCE

STANDARD(S) TO WHICH CONFORMITY IS DECLARED: IEC61326:2002

COMMUNICATIONS

RS-232 PORTS:
9-pin: DCE (not electrically isolated) for computer or non-CSI modem connection.
COM1 to COM2: Two independent Tx/Rx pairs on control ports (non-isolated); 0 to 5 Vdc UART
Baud Rate: selectable from 300 bps to 115.2 kbps.
Default Format: 8 data bits; 1 stop bits; no parity
Optional Formats: 7 data bits; 2 stop bits; odd, even parity

CS I/O PORT: Interface with CSI telecommunication peripherals

SDI-12: Digital control ports 1 or 3 are individually configured and meet SDI-12 Standard version 1.3 for datalogger mode. Up to ten SDI-12 sensors are supported per port.

PROTOCOLS SUPPORTED: PakBus, Modbus, DNP3, FTP, HTTP, XML, POP3, SMTP, Telnet, NTCIP, NTP, SDI-12, SDM

SYSTEM

PROCESSOR: Renesas H8S 2322 (16-bit CPU with 32-bit internal core running at 7.4 MHz)

MEMORY: 2 MB of Flash for operating system; 4 MB of battery-backed SRAM for CPU usage, program storage and final data storage

RTC CLOCK ACCURACY: ±3 min. per year. Correction via GPS optional.

RTC CLOCK RESOLUTION: 10 ms

SYSTEM POWER REQUIREMENTS

VOLTAGE: 9.6 to 16 Vdc

EXTERNAL BATTERIES: 12 Vdc nominal (power and connection is reverse polarity protected)

INTERNAL BATTERIES: 1200 mAh lithium battery for clock and SRAM backup, typically provides 3 years of backup

TYPICAL CURRENT DRAIN:
Sleep Mode: 0.7 mA typical; 0.9 mA max.
1 Hz Sample Rate (1 fast SE meas.): 1 mA
100 Hz Sample Rate (1 fast SE meas.): 16.2 mA
100 Hz Sample Rate (1 fast SE meas. w/RS-232 communication): 27.6 mA
CR1000KD or CR850 Keyboard Display On (no backlight): add 7 mA to current drain
CR1000KD or CR850 Keyboard Display On (backlight on): add 100 mA to current drain

PHYSICAL

DIMENSIONS: 24.1 x 10.4 x 5.1 cm (9.5 x 4.1 x 2 in.); additional clearance required for cables and leads.

WEIGHT (datalogger + base): 0.7 kg (1.5 lb)

WARRANTY

3 years against defects in materials and workmanship.

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Appendix D

AET Project No. 01-05719

Geotechnical Report Limitations and Guidelines for Use

D.1 REFERENCE

This appendix provides information to help you manage your risks relating to subsurface problems which are caused by construction delays, cost overruns, claims, and disputes. This information was developed and provided by ASFE[1], of which, we are a member firm.

D.2 RISK MANAGEMENT INFORMATION

D.2.1 Geotechnical Services are Performed for Specific Purposes, Persons, and Projects

Geotechnical engineers structure their services to meet the specific needs of their clients. A geotechnical engineering study conducted for a civil engineer may not fulfill the needs of a construction contractor or even another civil engineer. Because each geotechnical engineering study is unique, each geotechnical engineering report is unique, prepared solely for the client. No one except you should rely on your geotechnical engineering report without first conferring with the geotechnical engineer who prepared it. An no one, not even you, should apply the report for any purpose or project except the one originally contemplated.

D.2.2 Read the Full Report

Serious problems have occurred because those relying on a geotechnical engineering report did not read it all. Do not rely on an executive summary. Do not read selected elements only.

D.2.3 A Geotechnical Engineering Report is Based on A Unique Set of Project-Specific Factors

Geotechnical engineers consider a number of unique, project-specific factors when establishing the scope of a study. Typically factors include: the client's goals, objectives, and risk management preferences; the general nature of the structure involved, its size, and configuration; the location of the structure on the site; and other planned or existing site improvements, such as access roads, parking lots, and underground utilities. Unless the geotechnical engineer who conducted the study specifically indicates otherwise, do not rely on a geotechnical engineering report that was:

- not prepared for you,
- not prepared for your project,
- not prepared for the specific site explored, or
- completed before important project changes were made.

Typical changes that can erode the reliability of an existing geotechnical engineering report include those that affect:

- the function of the proposed structure, as when it's changed from a parking garage to an office building, or from a light industrial plant to a refrigerated warehouse,
- elevation, configuration, location, orientation, or weight of the proposed structure,
- composition of the design team, or
- project ownership.

As a general rule, always inform your geotechnical engineer of project changes, even minor ones, and request an assessment of their impact. Geotechnical engineers cannot accept responsibility or liability for problems that occur because their reports do not consider developments of which they were not informed.

D.2.4 Subsurface Conditions Can Change

A geotechnical engineering report is based on conditions that existed at the time the study was performed. Do not rely on a geotechnical engineering report whose adequacy may have been affected by: the passage of time; by man-made events, such as construction on or adjacent to the site; or by natural events, such as floods, earthquakes, or groundwater fluctuations. Always contact the geotechnical engineer before applying the report to determine if it is still reliable. A minor amount of additional testing or analysis could prevent major problems.

1 ASFE, 8811 Colesville Road/Suite G106, Silver Spring, MD 20910
Telephone: 301/565-2733 : www.asfe.org

D.2.5 Most Geotechnical Findings Are Professional Opinions

Site exploration identified subsurface conditions only at those points where subsurface tests are conducted or samples are taken. Geotechnical engineers review field and laboratory data and then apply their professional judgment to render an opinion about subsurface conditions throughout the site. Actual subsurface conditions may differ, sometimes significantly, from those indicated in your report. Retaining the geotechnical engineer who developed your report to provide construction observation is the most effective method of managing the risks associated with unanticipated conditions.

D.2.6 A Report's Recommendations Are Not Final

Do not overrely on the construction recommendations included in your report. Those recommendations are not final, because geotechnical engineers develop them principally from judgment and opinion. Geotechnical engineers can finalize their recommendations only by observing actual subsurface conditions revealed during construction. The geotechnical engineer who developed your report cannot assume responsibility or liability for the report's recommendations if that engineer does not perform construction observation.

D.2.7 A Geotechnical Engineering Report Is Subject to Misinterpretation

Other design team members' misinterpretation of geotechnical engineering reports has resulted in costly problems. Lower that risk by having your geotechnical engineer confer with appropriate members of the design team after submitting the report. Also retain your geotechnical engineer to review pertinent elements of the design team's plans and specifications. Contractors can also misinterpret a geotechnical engineering report. Reduce that risk by having your geotechnical engineer participate in prebid and preconstruction conferences, and by providing construction observation.

D.2.8 Do Not Redraw the Engineer's Logs

Geotechnical engineers prepare final boring and testing logs based upon their interpretation of field logs and laboratory data. To prevent errors or omissions, the logs included in a geotechnical engineering report should never be redrawn for inclusion in architectural or other design drawings. Only photographic or electronic reproduction is acceptable, but recognizes that separating logs from the report can elevate risk.

D.2.9 Give Contractors a Complete Report and Guidance

Some owners and design professionals mistakenly believe they can make contractors liable for unanticipated subsurface conditions by limiting what they provide for bid preparation. To help prevent costly problems, give contractors the complete geotechnical engineering report, but preface it with a clearly written letter of transmittal. In the letter, advise contractors that the report was not prepared for purposes of bid development and that the report's accuracy is limited; encourage them to confer with the geotechnical engineer who prepared the report (a modest fee may be required) and/or to conduct additional study to obtain the specific types of information they need to prefer. A prebid conference can also be valuable. Be sure contractors have sufficient time to perform additional study. Only then might you be in a position to give contractors the best information available to you, while requiring them to at least share some of the financial responsibilities stemming from unanticipated conditions.

D.2.10 Read Responsibility Provisions Closely

Some clients, design professionals, and contractors do not recognize that geotechnical engineering is far less exact than other engineering disciplines. This lack of understanding has created unrealistic expectations that have led to disappointments, claims, and disputes. To help reduce the risk of such outcomes, geotechnical engineers commonly include a variety of explanatory provisions in their report. Sometimes labeled "limitations" many of these provisions indicate where geotechnical engineers' responsibilities begin and end, to help others recognize their own responsibilities and risks. Read these provisions closely. Ask questions. Your geotechnical engineer should respond fully and frankly.

D.2.11 Geoenvironmental Concerns Are Not Covered

The equipment, techniques, and personnel used to perform a geoenvironmental study differ significantly from those used to perform a geotechnical study. For that reason, a geotechnical engineering report does not usually relate any

geoenvironmental findings, conclusions, or recommendations; e.g., about the likelihood of encountering underground storage tanks or regulated contaminants. Unanticipated environmental problems have led to numerous project failures. If you have not yet obtained your own geoenvironmental information, ask your geotechnical consultant for risk management guidance. Do not rely on an environmental report prepared for someone else.