COLORADO
Department of Transportation

Applied Research and Innovation Branch

INSTALLATION SUMMARY REPORT: GRS INSTRUMENTATION ON I-70 OVER SMITH ROAD

Shannon & Wilson, Inc.

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16. Abstract

This report presents a summary of the I-70 over Smith Road GRS Instrumentation Project (the project) in Aurora, Colorado. The report summarizes the instruments used, installation means and methods, and a discussion on the web-based data interface. CDOT prepared a preliminary instrumentation design for the project advertisement plans and prior to our task order authorization. Shannon & Wilson provided the design, installation, automatic data acquisition system (ADAS), and the online integrated database management system (webIDMS) for the project. The project included the installation of all instruments, power and communication systems, and connection of temporary and final data logger locations.

Implementation Statement

The intent of the ADAS and instrumentation at this site is to provide data and evaluation of the geosynthetic reinforced soil (GRS) performance within the abutment and walls. This project is performed to support CDOT research study on GRS structures.

17. Keywords
data logger, automatic data acquisition system, integrated database management system, pressure cells, multiplexer, geosynthetic reinforced soil, abutment

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EXECUTIVE SUMMARY

This report presents a summary of the I-70 over Smith Road GRS Instrumentation Project (the project) in Aurora, Colorado. A comprehensive instrumentation program was installed at the project location to monitor a geosynthetic reinforced soil (GRS) abutment. The report summarizes the instruments used, installation means and methods, and a discussion on the web-based data interface.

CDOT prepared a preliminary instrumentation design for the project advertisement plans prior to our task order authorization. Shannon & Wilson provided the design, installation, automatic data acquisition system (ADAS), and the online integrated database management system (webIDMS) for the project. The project included the installation of all instruments, power and communication systems, and connection of temporary and final data logger locations.

The intent of the ADAS and instrumentation at this site is to provide data and evaluation of the GRS performance within the abutment and walls.

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1. INTRODUCTION

This report presents a summary of the I-70 over Smith Road GRS Instrumentation Project (the project) in Aurora, Colorado. The report summarizes the instruments used, installation means and methods, and a discussion on the web-based data interface. Our services were conducted in general accordance with our Task Order Number 1 and Task Order Number 1 Time Extension, dated October 8, 2013 and July 27, 2015, respectively.

CDOT prepared a preliminary instrumentation design for the project advertisement plans prior to our task order authorization. Shannon & Wilson provided the design, installation, automatic data acquisition system (ADAS), and the online integrated database management system (webIDMS) for the project. The project included the installation of all instruments, power and communication systems, and connection of temporary and final data logger locations. Ames Construction, Inc. (Ames) was the general contractor for bridge construction.

1.1 Site and Project Description

The project is located in Aurora, Colorado along Interstate 70 (I-70), as shown on Figure 1. The project includes the construction of two multi-span bridges that convey I-70 over Smith Road and the Union Pacific Railroad, replacing outdated and underperforming bridges. The new structures are founded on HP 12x84 H-piles at the northern abutment (Abutment 1), 36-inch diameter drilled shafts at Pier 2 and 3, and geosynthetic reinforced soil (GRS) at the southern abutment (Abutment 4). A driven sheet pile facing with tie-back anchor rods is used at each abutment.

For GRS construction at Abutment 4, the sheet pile facing was driven prior to excavation of the GRS backfill area. After driving the sheet pile, excavation was completed to a final bench where deadmen sheet piles were driven. Tie rods were then installed between the front face sheet piles and deadmen sheet piles. GRS backfill was completed in 4-inch lifts with full length reinforcement every 12 inch lift and a cast in place concrete abutment seat was placed at the top of the GRS zone.

Wall DH is located at the northwest corner of the project (Figure 2), adjacent to Abutment 1 and below the east bound lanes of I-70. The majority of the masonry block wall was constructed using geogrid reinforcement with 24-inch spacing. Between STA 15+40 and 16+00 the wall was constructed using geosynthetic fabric reinforcement with 8-inch spacing.

2. INSTRUMENTATION INSTALLATION

The project included the installation of five instrumentation lines at various locations of the project site, separated into three installation phases as follows:

Phase 1

- Two instrumentation lines (I1 and I2) were installed for the westbound I-70 bridge within the GRS backfill at approximate abutment stationing STA 1+73.5 and 1+93, respectively.
- Each line included vertical earth pressure cells, horizontal earth pressure cells, tie-rod strain gages, and crackmeters.
- Line I1 included an in-place inclinometer system called ShapeAccellArray (SAA), installed within a 3-inch diameter steel pipe welded to the back face of the sheet pile.
- Line I1 also included Tencate GeoDetect fiber optic strain fabric layers. The GeoDetect utilizes multiple fiber optic sensors for strain measurement.

Phase 2

- Instrumentation Line I3 was installed within the GRS backfill at Abutment 4 for the eastbound I-70 bridge (Phase 2) at STA 2+93.
- Line I3 included vertical earth pressure cells, horizontal earth pressure cells, and tie-rod strain gages.

Wall DH

- Two instrumentation lines (I4 and I5) were installed within wall DH at STA 15+59 and 15+77, respectively.
- Instrumentation included vertical earth pressure cells, horizontal earth pressure cells, and strain instrumented fabric.

Installation and instrumentation information for these sections is discussed further in Appendix A. Figures 3 and 4 present the locations of each instrument within the constructed sections. Three separate data loggers were installed as part of the monitoring project, and details of the monitoring systems are discussed in Appendix B. Tables 1 through 3 present a timeline of the major instrumentation milestones for each of the three installation events. Refer to Appendix C for the overall construction schedule provided by CDOT and Ames.

3. ADAS INSTALLATION

3.1 Instrument Cable Routing

The Abutment 4 instrument signal leads were routed to five multiplexer boxes. Multiplexers serve as a junction for the multiple instrument input signal cables, combining them into a collective signal cable for data transmission. PVC conduit containing the instrument signal leads for Instrument Lines 1 and 2 pass through the girder diaphragm concrete to the first four multiplexers installed on the east facing sheet pile wall of Abutment 4. The instrument leads for Instrument Line 3 were routed in conduit behind the sheet pile within the coping to the east, extended through the sheetpile, and routed to Multiplexer 5 on the concrete coping of west-bound bridge. Multiconductor cable was used to connect each of the multiplexers together and then connect to the data logger installed on the wing-wall coping at the southeast corner of the abutment (Figure 2). The data loggers are used to record and store all data from the instruments.

Fiber optic leads from Instrument Line 1 were routed through PVC conduit to the fiber optic data logger, which is installed at the base of the slope at the southeast corner of Abutment 4.

Wall DH instrument leads were routed through PVC conduit over the precast coping and down to a multiplexer box installed on the masonry block wall for each instrument line. Multiconductor cables were then routed from the multiplexers through conduit to the Wall DH data logger, installed between the multiplexers.

3.2 Data Logger and Multiplexer Installation

Automated monitoring of the instruments is being performed by three separate data logging systems. The first data logger system monitors the vibrating wire instruments and the ShapeAccelArray at Abutment 4. The second data logger collects the fiber optic data at Abutment 4. The third data logger collects all vibrating wire and strain data at Wall DH. Manual readings of the instruments were taken during construction prior to the data logger installation. Each data logger utilizes cellular modems for remote data transmission. A detailed discussion on all components and the installation process of the data loggers is included in Appendix B. In addition, cut sheets of all components associated with the data loggers are included in Appendix B.

4. AUTOMATED DATA MANAGEMENT AND MONITORING

Instrument readings from the three project data loggers are managed and monitored using webIDMS, a web-based application developed by Shannon & Wilson for collecting, processing, and displaying geotechnical instrumentation data. The application connects to each data logger via the internet once per hour to download the accumulated instrument readings. The application converts the downloaded readings to results in engineering units and the results, date and time of the readings, and the instrument readings are stored in the application's database.

The webIDMS database also stores the individual instrument calibration and conversion data needed to convert instrument readings to engineering units. This information was uploaded from quality control spreadsheets developed during installation and testing of the project instrumentation systems. Initial results from webIDMS were compared to results from the quality control spreadsheets to confirm that calibration data and conversion algorithms in webIDMS are correct.

Project instrumentation data is monitored via the webIDMS user interface (http://www.shanwil-idms.com/). The password-controlled user interface enables CDOT and others to view and graph the instrumentation data and to manage instrument calibration data. The graphs include time-history plots of results in engineering units as well as raw instrument reading units. At the time of this report, the webIDMS is being maintained by Shannon & Wilson and will continue to collect data as well as be available for data archive review. In addition, a CD with the data archive for each instrument from the initiation of data collection through February 2016 is provided in Appendix D. A description of the electronic data format and organization is included with the electronic files included on the CD in Appendix D.

In addition to time-histories of individual ShapeAccelArray sensors on the webIDMS, an array summary can be displayed in a displacement vs. elevation graph with multiple dates per graph. The displacement data shown for the user-selected dates in this graph are average displacements for the selected dates. Sample output graphs are provided in Appendix B as Photographs B-9 and B-10 as well as Figure D-10 in Appendix D.

6. RECOMMENDATIONS FOR FUTURE INSTRUMENTATION SYSTEMS

4.1 Scoping and Procurement

For this instrumentation installation, Shannon & Wilson worked as a consultant to the CDOT Geohazard and Research Programs under a Non-Project Specific (NPS) contract with CDOT. The Geohazard Program involvement was primarily related to task order initiation and invoice processing of Shannon & Wilson work. The Research Program involvement was involved in the scope formulation and ongoing review of instrumentation installation progress. The general contractor for bridge construction, Ames, worked under a separate construction contract with CDOT. For the construction work that interfaced with the GRS project activities, Ames used subcontractors for MSE and GRS block wall construction. The CDOT Project Engineer was tasked with administering the general contractor per the project plans and specifications. Additionally, the Project Engineer provided contractor coordination assistance between Shannon & Wilson and Ames.

During the initial project scoping, the CDOT Geohazard and Research Programs, Project Engineer, and Shannon & Wilson discussed means for instrumentation procurement and installation. At that time, the option for CDOT purchasing the instruments was discussed, but the administrative burden was judged to be a burden based on the different suppliers, cost of materials, and state purchasing rules. The options that were considered included the following:

1. Using a CDOT NPS contract to select a consultant for instrumentation installation, with the option for consultant purchase of instruments or general contractor purchase of instruments.
2. Using a Force Account or other bid item for the contractor to procure and install the instrumentation per plan under their contract with CDOT.
3. Issuing a request for proposals for a price based bid on instrumentation procurement and installation based on instrumentation plans.

The option selected by CDOT was the NPS consultant contract along with requiring the consultant to purchase the instruments. We understand that Options 2 and 3 above were not selected because of difficulty in developing final instrumentation plans and specifications because of the need for contractor input on coordination of activities and installation details. Additionally, the instrumentation purchase costs would have been marked up by up to 15 percent if purchased under a construction contract, while purchases under a consultant NPS contract are not allowed to have markup.

In our opinion, the selected option was the appropriate procurement process for this project because of the need for flexibility in coordination with the contractor and the ability to adjust the instrumentation plans based on contractor means and methods. For example, the SAA inclinometer was installed in a steel pipe that was welded to the sheet pile based on constructability input from the contractor during construction. The original installation plan consisting of PVC pipe installed as close as possible to the sheet piling was able to be quickly modified under the NPS contract format, versus the contract modification process that would be used with other procurement methods.

Based on the instrumentation installation process for this project, we recommend future projects consider contracting options that allow for flexibility to changes in the installation plans throughout the construction process. The contracting flexibility should consider modifications to instrument types and procurement changes after award and adjustment to labor budget in response to contractor schedules.

The Shannon & Wilson task order was scoped and authorized several months before advertisement for the general contractor. As a result, the instrumentation installation scope was developed without any input from the contractor. For future projects, we recommend developing the instrumentation installation scope with contractor input, if possible. This would reduce the number of assumptions that were made during the scoping of the instrumentation installation task order.

4.2 Scheduling

Progress of the instrumentation installation relies heavily on the contractor and subcontractor schedules. Working with contractors includes changing schedules, short notices, and various delays such as weather and third party agreements that are often out of contractor's control. These changes and delays caused several starts and stops of the instrumentation installation process that required additional labor hours that were not originally estimated in the instrumentation installation budget.

Due to the changing schedule and at the suggestion of the CDOT Project Engineer, we started attending weekly meetings for an overview of the upcoming project milestones and the three-week look ahead schedule that the contractor was required to provide. These weekly meetings also allowed for quick resolution to coordination issues between CDOT, Ames and their subcontractors, and Shannon & Wilson instrumentation staff. For example, when determining the Abutment 4 final data logger locations, discussion was held at the weekly meeting to come to a consensus on a reasonable final location for the data loggers based on continuing project constraints and feasible installation locations.

For future instrumentation projects, we recommend estimating a fixed labor amount per week of relevant construction for instrumentation installation staff to participate in coordination meetings or to individually contact key personnel for planning of work. Based on this project, approximately two hours per week was spent on scheduling and coordination. Additionally, the project specifications should include a provision for the contractor to include instrumentation activities on the look ahead schedule and provide the instrumentation team with updates to changes in the project schedule as they occur.

4.3 Roles and Responsibilities

As indicated above, there were several CDOT and contractor representatives involved in the administration of the instrumentation installation project. While the selected instrumentation installation procurement process was judged to be appropriate in the interest of CDOT, the contractor viewed the work as an item they could not control and was therefore concerned that instrumentation installation activities could impact their critical path activities.

After the construction kickoff meeting, a point of contact with the contractor was established to facilitate the instrumentation installation process with contractor construction activities.

On future instrumentation projects we recommend that the project specifications include the requirement for a contractor point of contact within the bid documents. Additionally, we recommend establishing a minor force account budget for the contractor to recover costs that could be associated with installation, such as short delays and assistance with general labor activities (e.g. welding, excavation of trenches). In our opinion, this may reduce the contractor concern with instrumentation activities impacting the project.

4.4 Geosynthetic Strain Measurement Type Discussion

The GeoDetect sytem is an emerging technology for measurement of strain in geosynthetics that was suggested for use on this project by FHWA. At this time, the only known full scale use of GeoDetect is for this project and another GRS project in Puerto Rico. Due to the limited use of this product in industry, there were challenges with the GeoDetect monitoring system installation. For example, the fiber optic interrogator requires a significant amount of power to operate, and the available space for a temporary data logger setup and its associated components was limited. As a result, during installation of the rigid sheet pile abutment facing and the general GRS construction, it was difficult to acquire timely data for reporting during the construction process. This challenge continued after the GRS backfill was completed due to the need to accommodate the relatively large solar panel and accompanying data logger on an active construction site. For future projects where a GeoDetect monitoring system is used, we would recommend a dedicated continuous power source at the project site be available, and specification of permanent and temporary data logger locations that will not be disrupted by construction site activities.

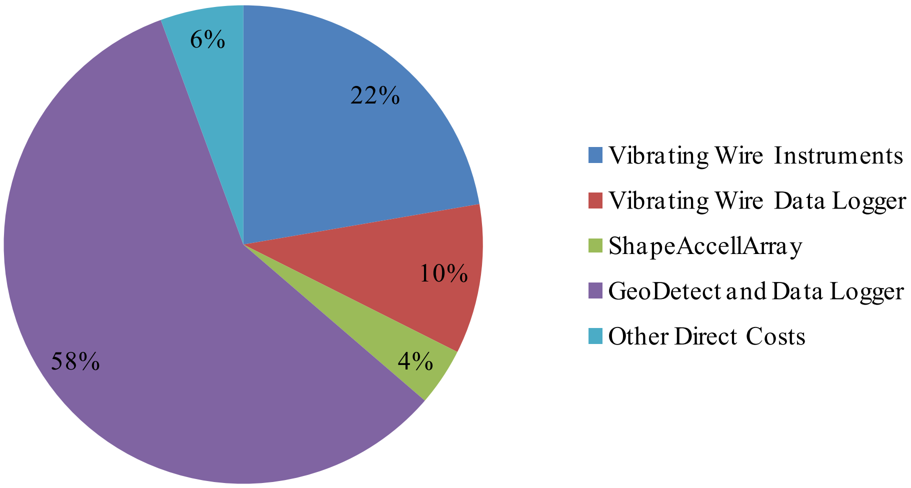
The GeoDetect system was originally scheduled for all phases of GRS features; however, in Phase 2 traditional foil resistance gages were used for strain measurement in Wall DH. The change to traditional strain gages was due to the long distance to the data logger and need for a conduit pipe on the I-70 bridge between the Wall DH instrumented wall section and the Abutment 4 Fiber Optic Data Logger. As a result, a second fiber optic data logger would have needed to be purchased, which was a prohibitive cost.

4.5 Instrumentation Costs

The total cost of geotechnical instrumentation for the project is $240,232, excluding labor and includes the following expenses:

- Vibrating Wire Instruments: $ 53,555
    - Includes all pressure cells, tie-rod strain gages, crackmeters, and traditional strain gages.
- Vibrating Wire Data Logger Setups and Cellular Communication: $ 26,008
    - Includes all multiplexers, data loggers, solar panels for vibrating wire instruments, and cellular communication.
- ShapeAccelArray: $ 9,370
    - All costs associated with the in place inclinometer installed on the backface of the sheet pile.
- GeoDetect and Data Logger: $ 139,539
    - Includes 9 Tencate GeoDetect strips, data logger, and solar panel.
- Other Direct Costs : $ 11,760
    - Installation supplies, contracted welding, and vehicle mileage.

The distribution of the instrumentation costs is presented in the graphic below.



As shown in the graphic, the GeoDetect system required a majority of the instrumentation budget. While the data from the GeoDetect system is reliable and of higher quality, there is a significant cost increase. For future projects, we recommend the selection of the geosynthetic strain measurement consider the tradeoff between data quality, post-installation reliability, and cost.

The project labor expense was approximately $200,000, which includes approximately 1,700 hours of time for instrumentation preparation, field installation activities, and moving of temporary and final data and communication locations. At times, two instrument installation technicians were required concurrently to assist with activities such as running wiring and instrument placement. The instrumentation installation project duration was over an 18 month construction duration. The remaining 300 hours on the project were associated with project management, drafting of plan sheets, reporting, and programing and ongoing maintenance of webIDMS data viewing portal.

In our opinion, the distribution between labor and instrumentation costs is relatively high and primarily due to the extension of the project schedule during Phase 1, which resulted in several short duration activities over a long period of construction. Conversely, the Phase 2 installation was more efficient due to a quicker construction schedule and communication and coordination improvements throughout the project.

7. CONCLUSION

The intent of the ADAS and instrumentation at this site is to provide data and evaluation of the GRS performance within the abutment and walls. Periodic maintenance will be necessary to verify continuity and quality of data measurements. We recommend visits to the site for the following tasks:

- Replace desiccant packs in enclosures (every 6 months),
- Replace batteries (as necessary),
- Clean solar panel surface (every 6 months),
- Service ADAS components as needed, and
- Trouble-shoot non-responsive instruments, or instruments providing irregular output.

8. LIMITATIONS

This report has been prepared for the exclusive use of CDOT and their project partners for the purpose of developing an understanding of the I-70 over Smith Road GRS Instrumentation project. This report is intended for informational use only to assist CDOT in understanding the instruments used, installation means and methods, and the web-based data interface. The scope of our services did not include engineering analysis of the data and we make no warranty, express or implied, for the data provided.

TABLE 1
PHASE 1 ABUTMENT 4 INSTRUMENTATION INSTALLATION SCHEDULE

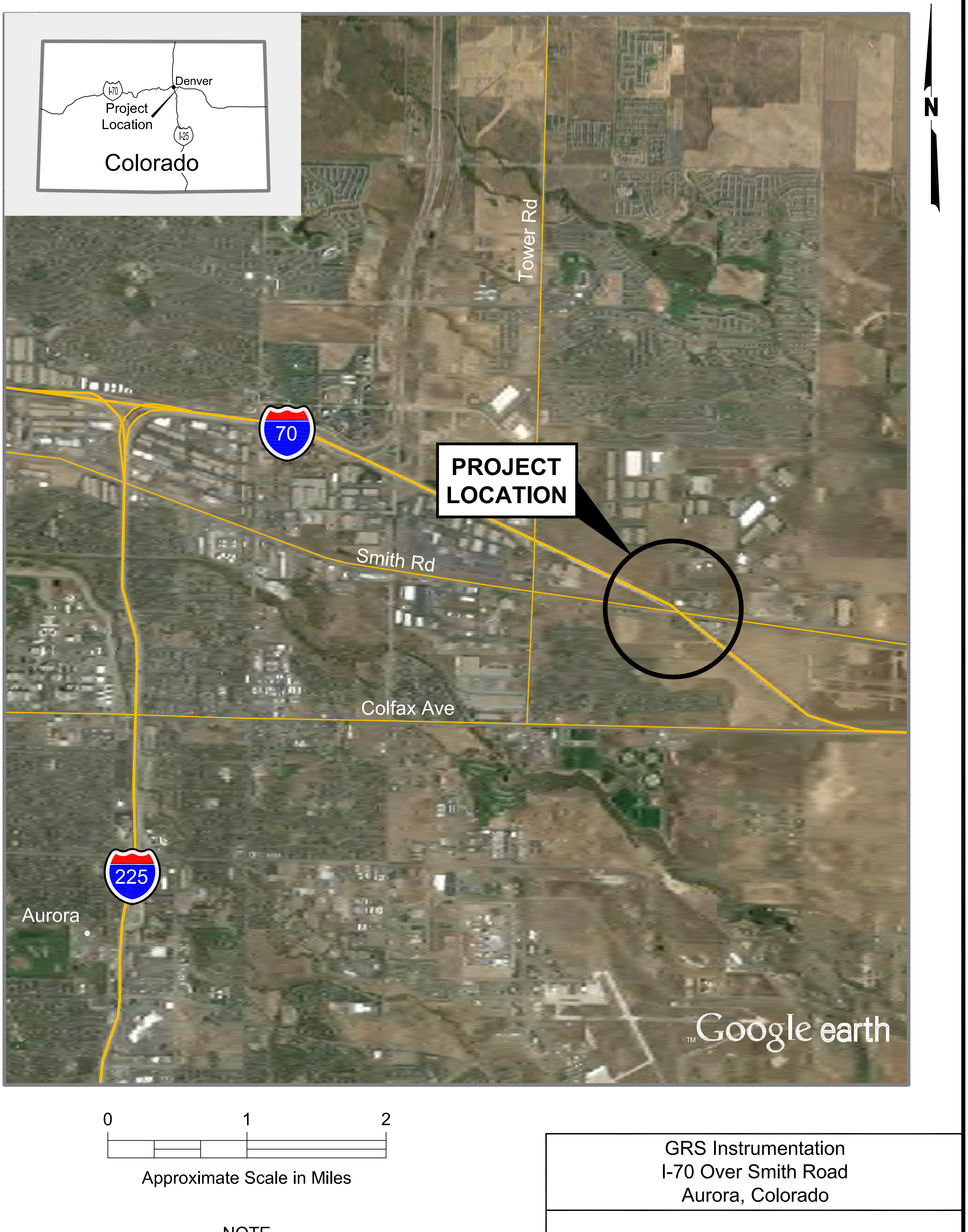
	Date	Task	Instrumentation Line	Location
Phase 1	February 13, 2014	Attend GRS Coordination Meeting		
	July 1, 2014	Pre install tie-rod strain gages		
	July 17, 2014	Pre install horizontal earth pressure cells	I1 and I2	Row 1
	July 21, 2014	Install vertical earth pressure cells	I1 and I2	Row 1
	July 21, 2014	Install half length GeoDetect	I1	Row 1
	August 13, 2014	Pre install horizontal earth pressure cells	I1 and I2	Row 2
	August 13, 2014	Exhume fabric sample	I1 and I2	Sample 1
	August 13, 2014	Install full length GeoDetect	I1	Row 2
	August 14, 2014	Install vertical earth pressure cells	I1 and I2	Row 2
	August 14, 2014	Install half length GeoDetect	I1	Row 2
	August 14, 2015	Exhume fabric sample	I1 and I2	Sample 2
	August 18, 2014	Pre install horizontal earth pressure cells	I1 and I2	Row 3
	August 20, 2014	Exhume fabric sample	I1 and I2	Sample 3
	August 20, 2014	Install full length GeoDetect	I1	Row 3
	August 20, 2014	Install half length GeoDetect	I1	Row 3
	August 21, 2014	Exhume fabric sample	I1 and I2	Sample 4
	August 27, 2014	Exhume fabric sample	I1 and I2	Sample 5
	August 27, 2014	Install full length GeoDetect	I1	Row 4
	September 3, 2014	Install vertical earth pressure cells	I1 and I2	Row 4
	September 3, 2014	Install half length GeoDetect	I1	Row 4
	September 19, 2014	Install ShapeAccelArray	I1	
	October 8, 2014	Complete temporary vibrating wire data logger setup		
	October 24, 2014	Pre install horizontal earth pressure cells	I1 and I2	Row 5 and 6
	October 28, 2014	Install full length GeoDetect	I1	Row 5
	October 28, 2014	Install vertical earth pressure cells	I1 and I2	Row 5
	October 30, 2014	Install crack meters	I1 and I2	
	November 6, 2014	Complete temporary fiber optic data logger setup		
	March 14, 2015	Install vertical earth pressure cells	I1 and I2	Row 6
	March 14, 2015	Install full length GeoDetect	I1	Row 6
	March 18, 2015	Install vertical earth pressure cells	I1 and I2	Row 7
	March 18, 2015	Install full length GeoDetect	I1	Row 7

TABLE 2
PHASE 2 ABUTMENT 4 INSTRUMENTATION INSTALLATION SCHEDULE

	Date	Task	Instrumentation Line	Location
Phase 2	July 13, 2015	Pre install tie rod strain gages	I3	
	July 22, 2015	Pre install horizontal earth pressure cells	I3	Row 1
	August 5, 2015	Complete final vibrating wire data logger setup	I1, I2 and I3	Abutment 4 coping
	August 7, 2015	Pre install horizontal earth pressure cells	I3	Row 2 and 3
	August 11, 2015	Install full length GeoDetect	I3	Row 3
	August 14, 2015	Install full length GeoDetect	I3	Row 4

TABLE 3
WALL DH INSTRUMENTATION INSTALLATION SCHEDULE

	Date	Task	Instrumentation Line	Location
Wall DH	September 21, 2015	Install strain fabric	I4 and I5	Row 1
	September 21, 2015	Install horizontal earth pressure cells	I4 and I5	Row 1
	September 26, 2015	Install vertical earth pressure cells	I4 and I5	Row 1
	September 28, 2015	Install strain fabric	I4 and I5	Row 2
	September 28, 2015	Install horizontal earth pressure cells	I4 and I5	Row 2
	September 29, 2015	Install vertical earth pressure cells	I4 and I5	Row 2
	September 30, 2015	Install strain fabric	I4 and I5	Row 3
	September 30, 2015	Install horizontal earth pressure cells	I4 and I5	Row 3
	October 1, 2015	Install vertical earth pressure cells	I4 and I5	Row 3
	October 2, 2015	Install vertical earth pressure cells	I4 and I5	Row 4
	October 2, 2015	Install strain fabric	I4 and I5	Row 4
	October 2, 2015	Install horizontal earth pressure cells	I4 and I5	Row 4



NOTE

Map adapted from aerial imagery provided by Google Earth Pro, reproduced by permission granted by Google Earth ™ Mapping Service.

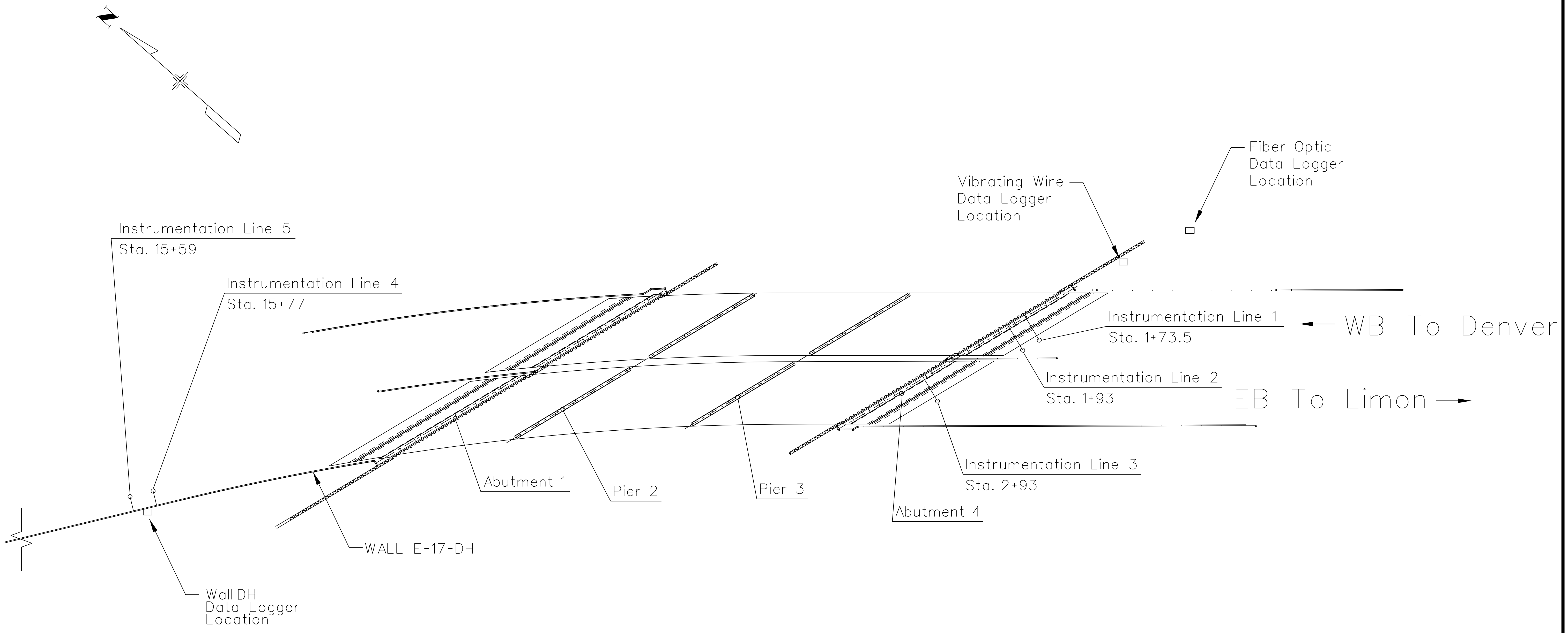
GRS Instrumentation
I-70 Over Smith Road
Aurora, Colorado

VICINITY MAP

February 2016 23-1-01395-001

SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

FIG. 1



LEGEND

—	Approximate Instrumentation Line Location
□	Approximate Data Logger Location

0 100 200

Scale in Feet

NOTES

Site plan adapted from CDOT file *16259INST_04_New ProfileDH12.dgn*

GRS Instrumentation
I-70 Over Smith Road
Aurora, Colorado

SITE PLAN

February 2016 23-1-01395-001

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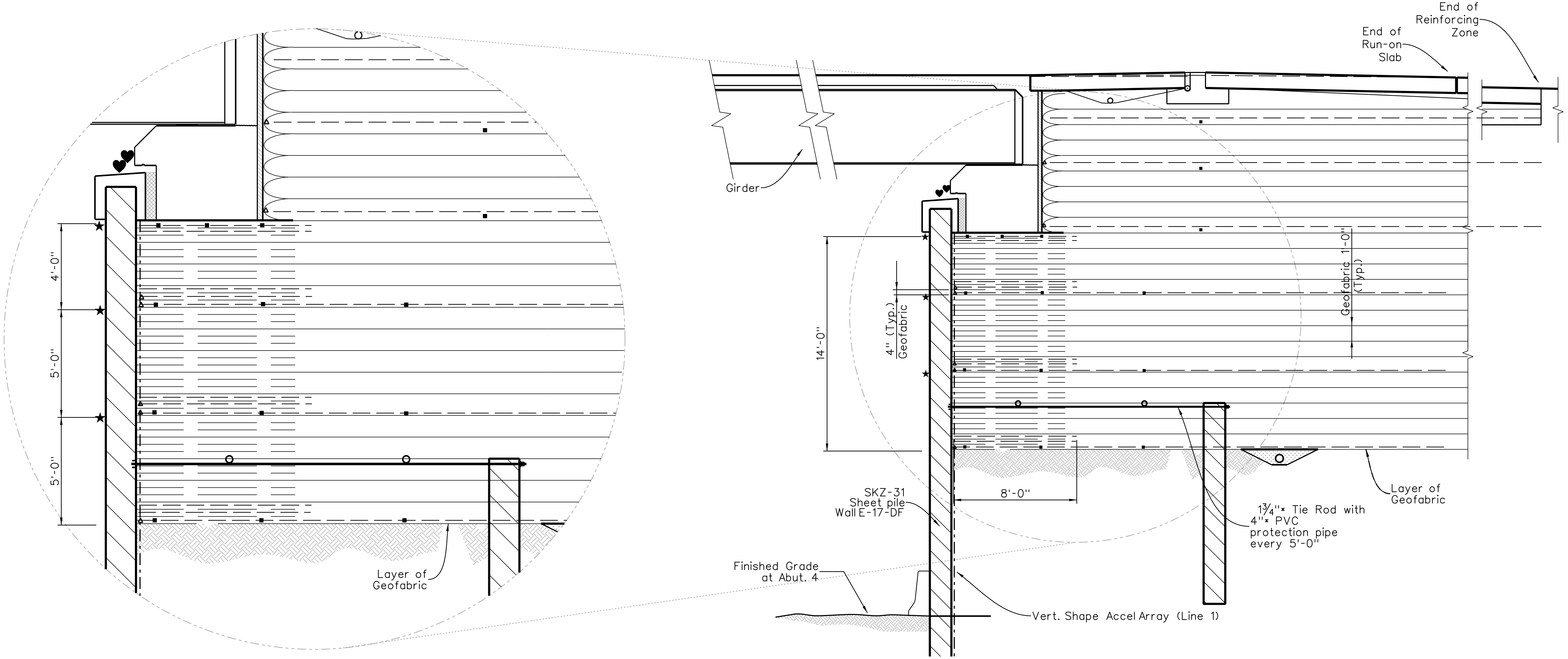
FIG. 2



IINSTRUMENTATION LINE 1 AND 2 (STATION 1+73.5 AND 1+93)
(PERPENDICULAR TO ABUTMENT NO. 4)

LEGEND

★ Survey Point
○ VW Strain Guage
△ Horiz. Earth Pres. Cell
■ Vert. Earth Pres. Cell
♥ VW Crack Meter
— — — Fiber Optic Strain Gage Strip (Instrumentation Line 1)
—·—·— Shape Accel Array (Instrumentation Line 1)

NOTES

Section view adapted from CDOT file *16259INST_02_GRSABUTMENT.dgn*

GRS Instrumentation
I-70 Over Smith Road
Aurora, Colorado

SECTION VIEW
ABUTMENT 4 PHASE 1

February 2016
23-1-01395-001

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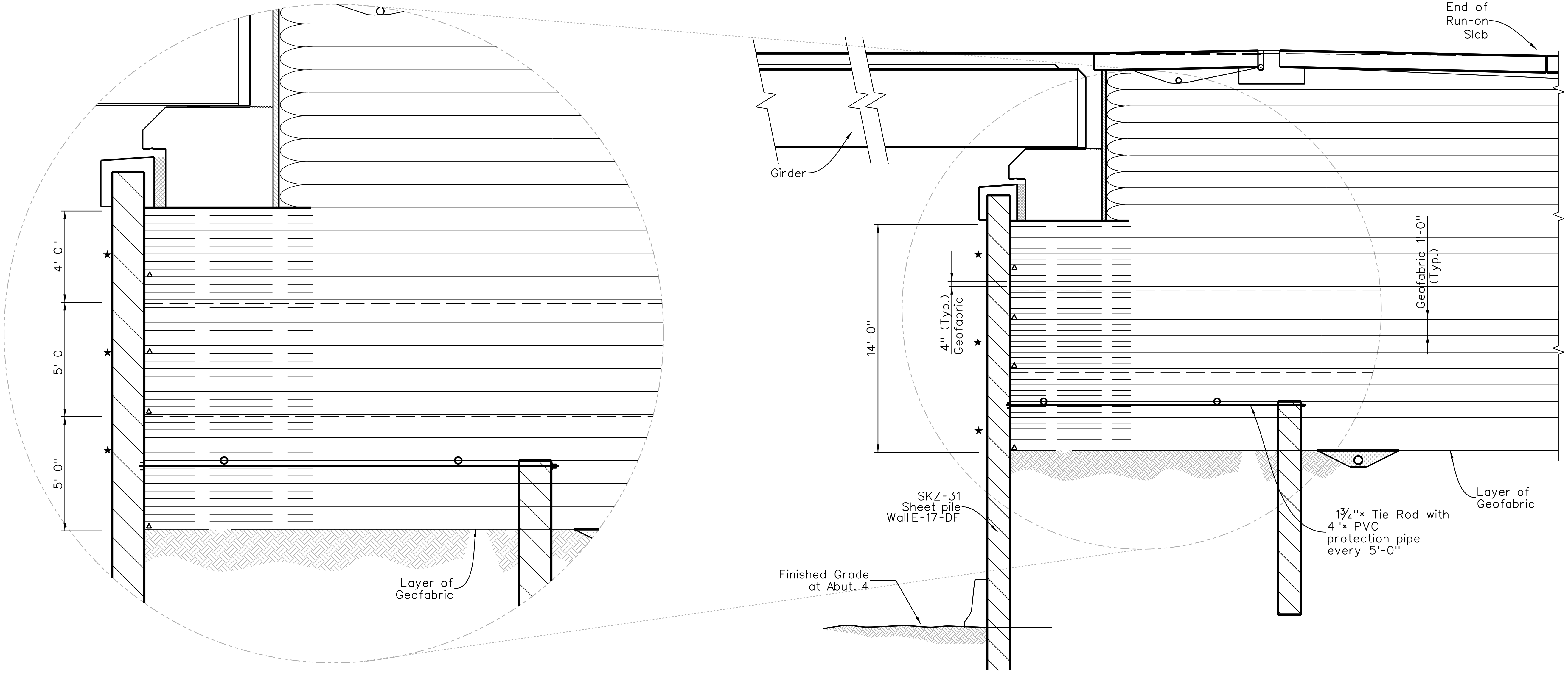
FIG. 3



INSTRUMENTATION LINE 3 (STATION 2+93)
(PERPENDICULAR TO ABUTMENT NO. 4)

LEGEND

△	Horiz. Earth Pres. Cell
— — —	Fiber Optic Strain Gage Strip
○	VW Strain Gage
★	Survey Point

NOTES

Section view adapted from CDOT file
16259INST_02_GRSABUTMENT.dgn

GRS Instrumentation
I-70 Over Smith Road
Aurora, Colorado

SECTION VIEW
ABUTMENT 4 PHASE 2

February 2016
23-1-01395-001

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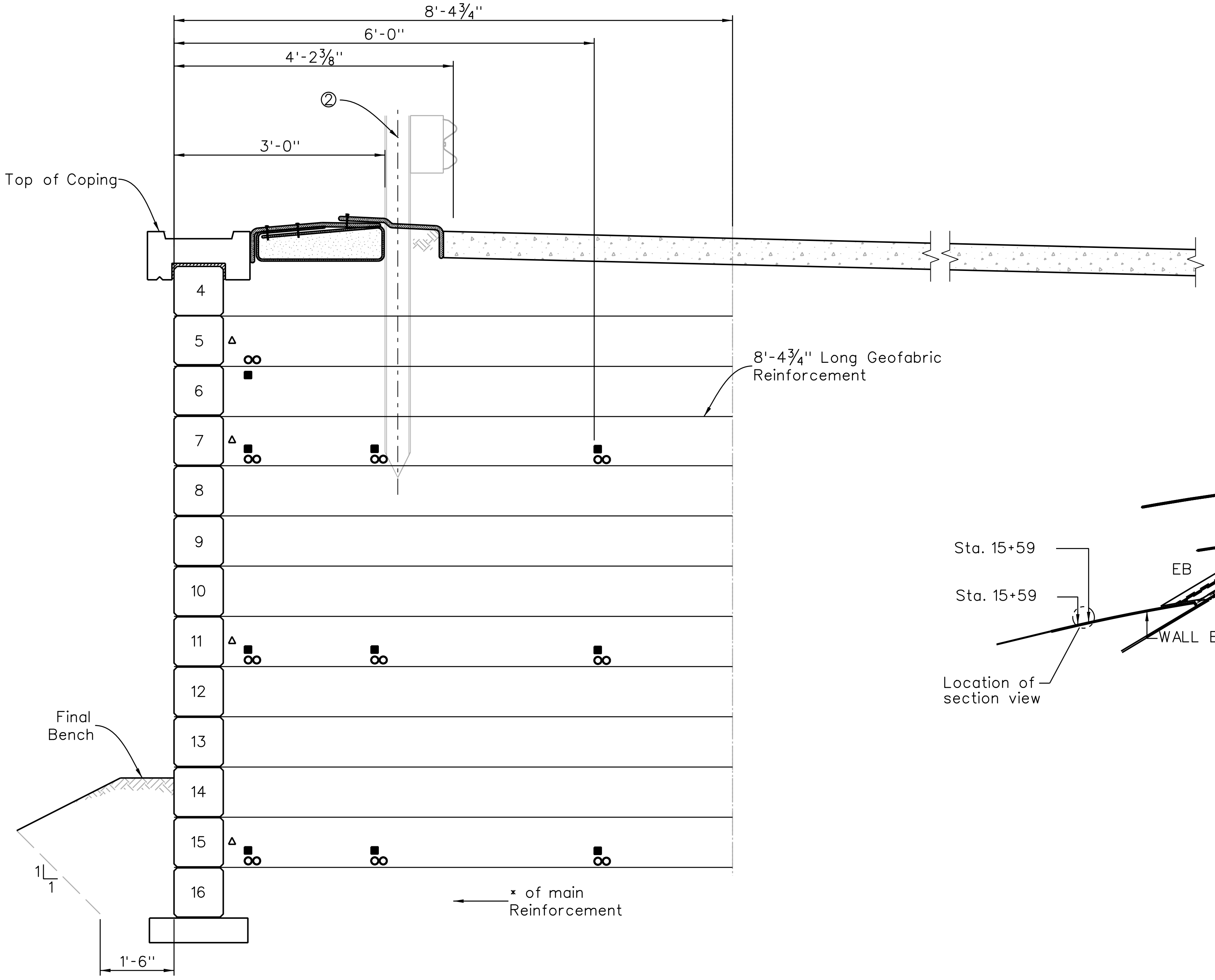
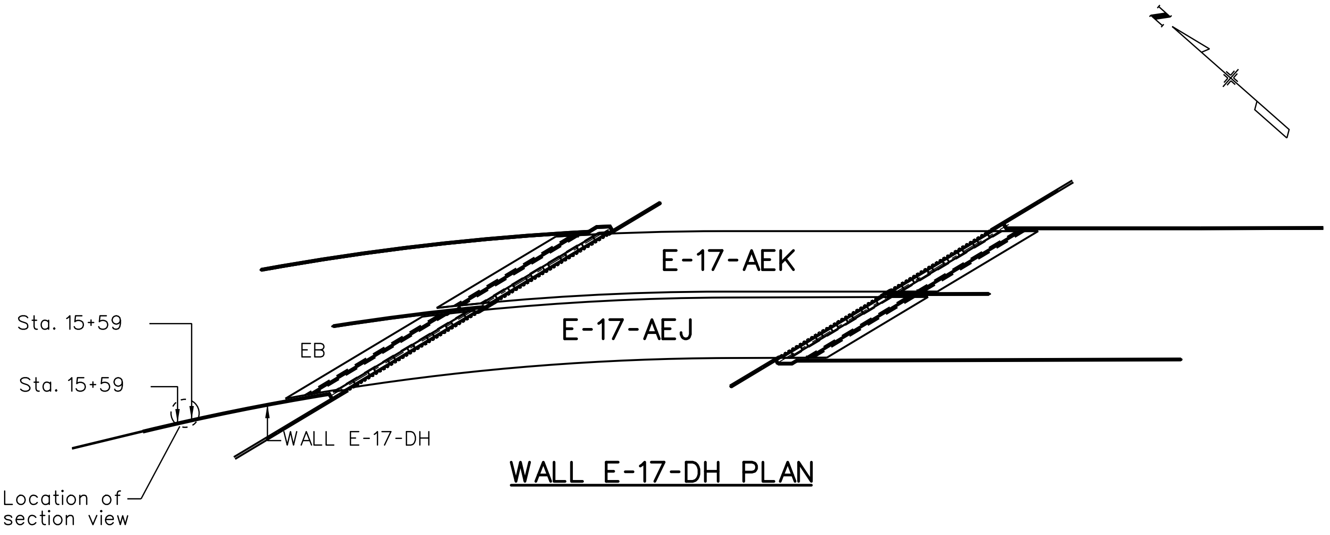
FIG. 4



SECTION VIEW AT INSTRUMENTATION LINE 4 AND 5 (STATION 15+77 AND 15+59)



WALL E-17-DH PLAN

NOTES:

① Geofabric reinforcement zone is 60'-0" in length (STA 15+40 to STA 16+00) for instrumentation purposes.

② Installation at guard rail post was coordinated to avoid the same spot as the instrumental gauges.

LEGEND

○ Strain Gauge

△ Pressure Cell (Horizontal)

■ Pressure Cell (Vertical)

NOTES

Section view adapted from CDOT file
16259INST_04_New ProfileDH12.dgn

GRS Instrumentation
I-70 Over Smith Road
Aurora, Colorado

SECTION VIEW
WALL DH

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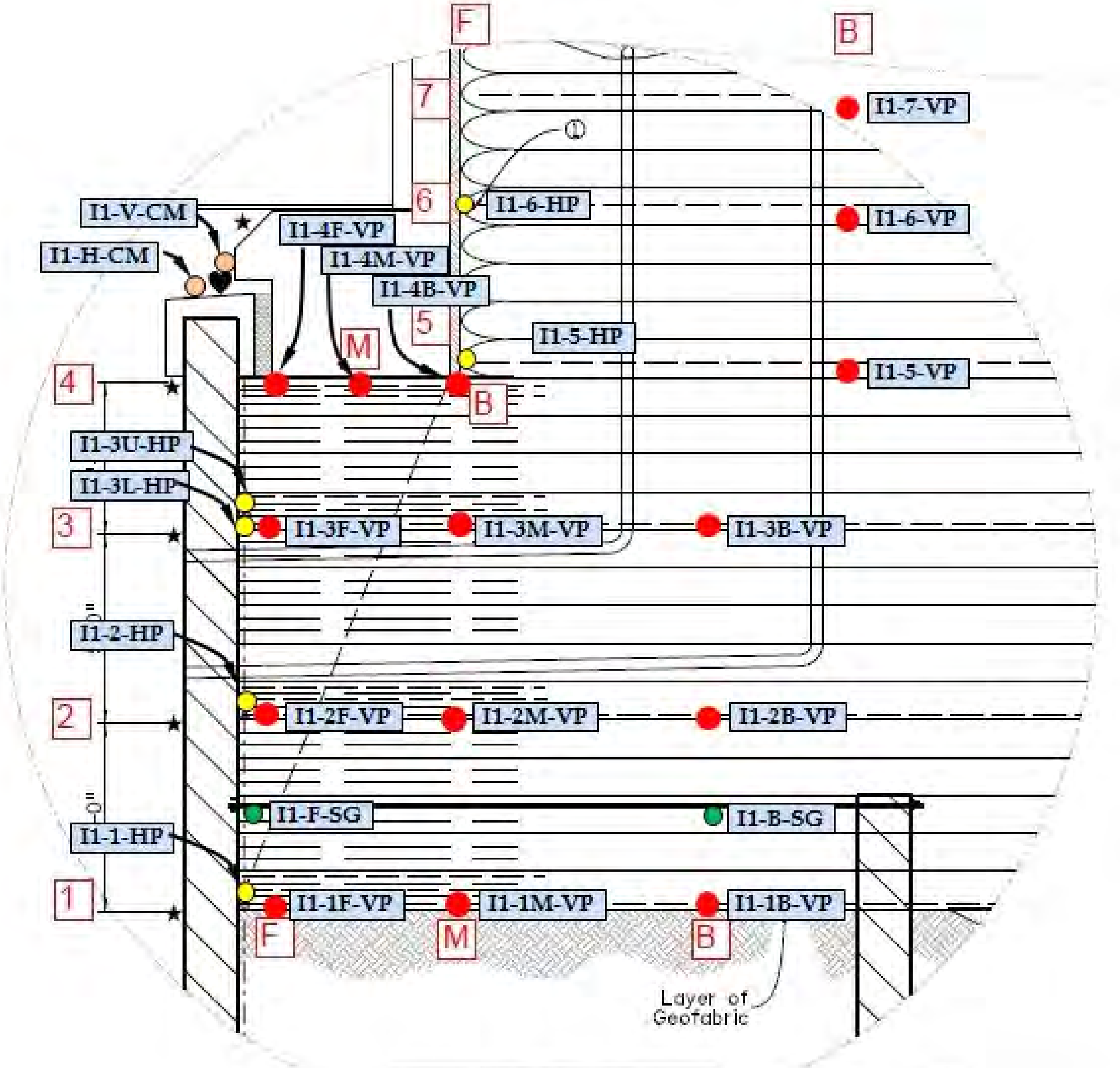
FIG. 5



INSTRUMENT LINE 1

LEGEND

I1-1F-VP	●	Vertical Earth Pressure Instrument Location and Designation
I1-1-HP	●	Horizontal Earth Pressure Instrument Location and Designation
I1-F-SG	●	Tierod Strain Gage Location and Designation
I1-V-CM	●	Crackmeter Instrument Location and Designation
— — — —		GeoDetect Fiber Optic Strain Fabric
— - — - — - —		ShapeAccellArray
1		Indicates instrument row
F		Indicates instrument column, F-Front, M-Middle, B-Back

NOTE

Instrument Line 2 contains the same layout, with the exception of the ShapeAcellArray and the GeoDetect Fiber Optic Strain Fabric which are not included in Line 2.

GRS Instrumentation
I-70 Over Smith Road
Aurora, Colorado

ABUTMENT 4
INSTRUMENT LAYOUT

February 2016 23-1-01395-001

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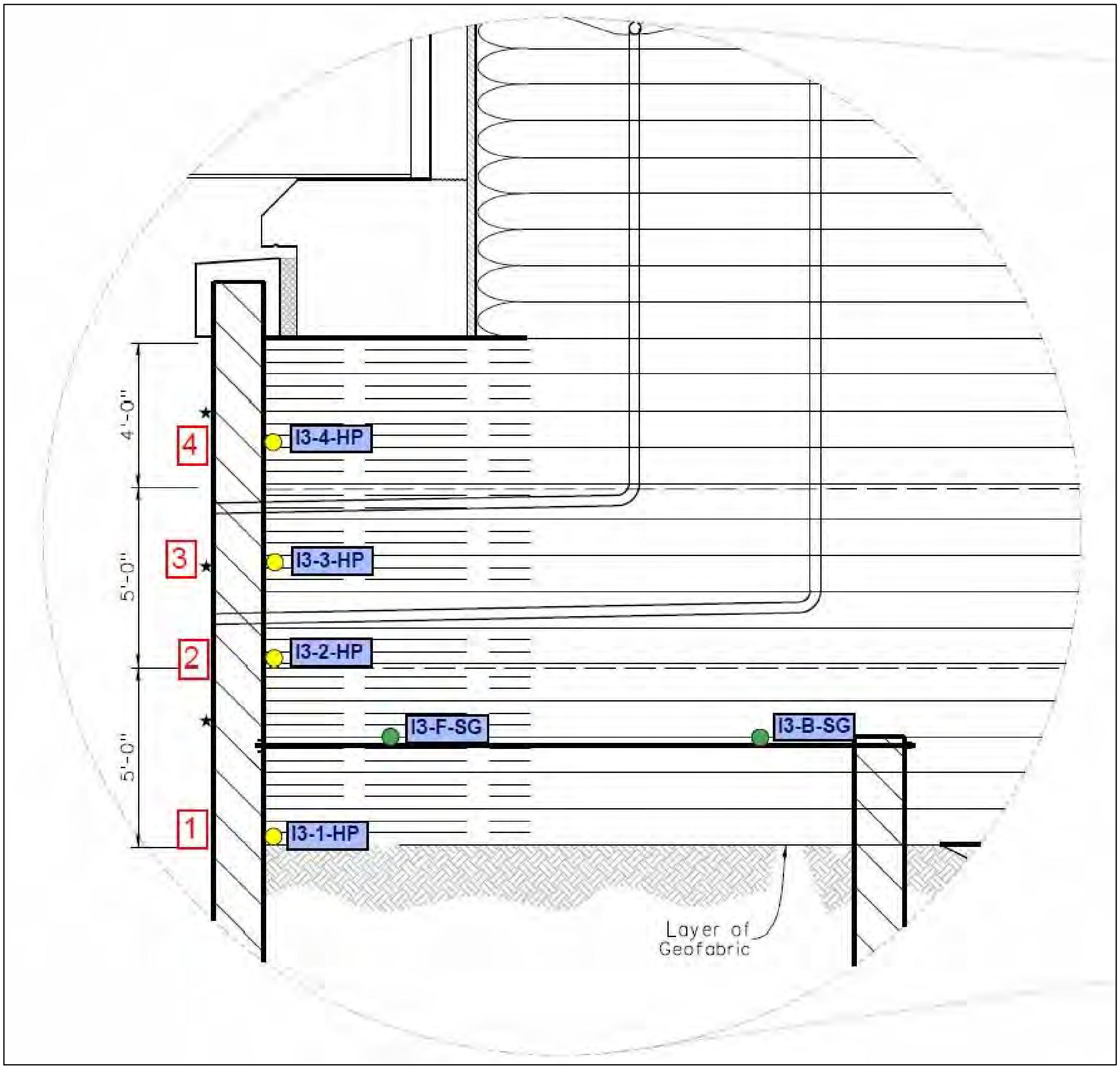
FIG. 6
Sheet 1 of 2



INSTRUMENT LINE 3

LEGEND

I3-1-HP ●	Horizontal Earth Pressure Instrument Location and Designation
I3-F-SG ●	Tierod Strain Gage Location and Designation
— — — —	GeoDetect Fiber Optic Strain Fabric
1	Indicates instrument row

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ABUTMENT 4
INSTRUMENT LAYOUT

February 2016 23-1-01395-001

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FIG. 6
Sheet 2 of 2

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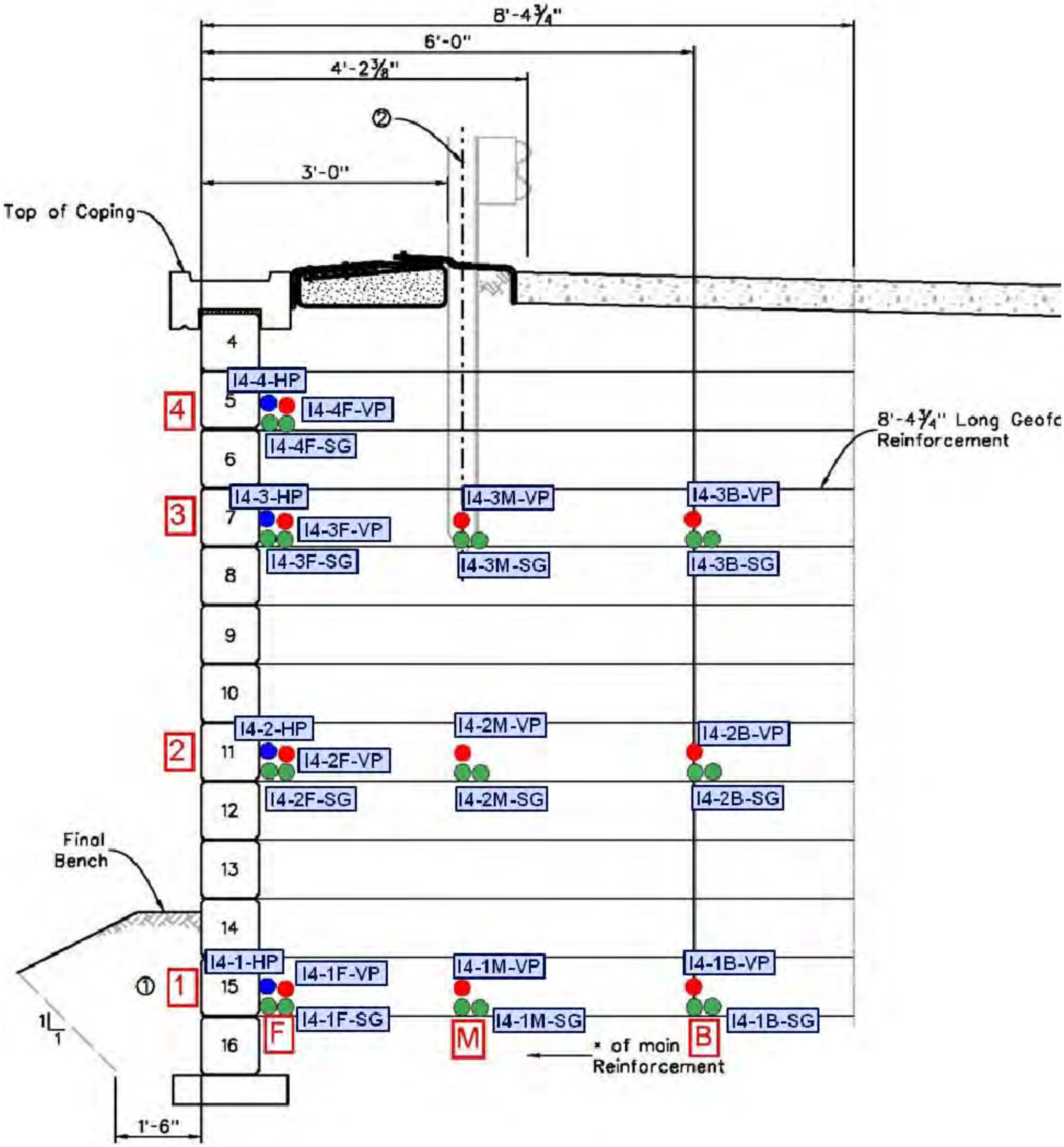

LEGEND

I4-1F-VP	🔴	Vertical Earth Pressure Instrument Location and Designation
I1-1-HP	🔵	Horizontal Earth Pressure Instrument Location and Designation
I1-F-SG	🟢	Fabric Strain Gage Location and Designation

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I-70 Over Smith Road
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WALL DH
INSTRUMENT LAYOUT

February 2016 23-1-01395-001

SHANNON & WILSON, INC.
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FIG. 7

Filename: I:\EF\23-1 DEN\01300s\01395 CDOT Geotech and Rockfall\001 - GRS Instruments (TO 1)\Report\Figures\Fig 7 Wall DH Instrument Layout.dwg Date: 01-18-2017 Login: jcg

APPENDIX A – INSTRUMENTS

TABLE OF CONTENTS

FIGURES

APPENDIX A – INSTRUMENTS

A.1 EARTH PRESSURE CELLS

We used Geokon Model 4800 and 4810 vibrating wire earth pressure cells for vertical and horizontal earth pressure measurement, respectively. Figure A-1 shows the manufacturer cut sheet for these instruments. The pressure cells consist of two stainless steel plates that sandwich a vessel of hydraulic fluid. The cell has a transducer that is attached to the vessel for pressure measurements. Horizontal pressure cells have a thick back plate to prevent bending when affixing the cell to a structure.

The horizontal earth pressure cells were attached to the sheet pile or abutment seat in Instrument Lines I1 through I3. Two horizontal pressure cells were installed directly adjacent to each other in rows 3 and 4 of I1 and I2 and are designated with an "L" for the lower cell and "U" for upper cell. The horizontal pressure cells at Wall DH were pre-installed on masonry blocks. The vertical earth pressure cells were typically installed in groups of three at varying distances from the sheet pile or masonry wall within a particular lift of fill.

Each instrument included 1/4 –inch-diameter PVC signal cable that was routed along the back of the structure to the appropriate multiplexer enclosure.

A.1.1 Horizontal Earth Pressure Cells - Installation

Prior to installation of the horizontal pressure cells, the sheet pile was pre-drilled for the four-hole mounting pattern of the pressure cell. A reading of each pressure cell was taken with a handheld readout prior to installing the pressure cell on the wall. A quick set mortar mix was then mixed and placed on the back of the pressure cell. Self-tapping metal screws were then used to secure the cell to the sheet pile. For pressure cells installed on the masonry block and abutment seat, wedge anchors were installed in the pre-drilled holes and used to secure the pressure cells. After the cells were installed, a second initial reading was taken with the handheld readout. Photo A-1 shows the horizontal pressure cell after installation on the sheet pile. Photograph A-2 shows the horizontal pressure cell installed on the masonry block in Wall DH.

A.1.2 Vertical Earth Pressure Cells - Installation

After the contractor completed compaction of the targeted lift, the compacted soil was removed to a minimum depth of 4 inches over an area of approximately 1.5 ft. by 3 ft. A thin bed of sand was then placed in the hole, followed by the pressure cell. Sand was then used to provide an additional 1 inch of cover for the pressure cell to help protect from potential damage from the Class 1 Structural Backfill placement for the embankment. The structural backfill was then used to fill in the remainder of the hole and compacted with a hand tamper. The initial reading was then taken with the handheld readout prior to additional fill being placed. Photograph A-3 shows the vertical pressure cells being installed within the Wall DH backfill.

A.2 TIE-ROD STRAIN GAGES

Strain gages were installed on the deadman tie-rod bars to measure changes in load during construction of the wall. The instruments were Geokon Model 4150 vibrating wire strain gages.

The strain gages were installed prior to the deadmen tie-rod installation. A smooth surface for the application of the strain gage end blocks was created on the tie-rods using a power grinder. The strain gage end blocks were then affixed to the bar using Loctite 410 instant adhesive and Loctite 712 accelerant mist spray. A cover plate was then placed over the strain gage for protection. The signal leads for each gage were then zip-tied to the tie-rod towards the front sheet pile. An initial readout of the strain gage was taken after the adhesive had cured. The contractor then covered the tie-rod in tar, placed in protective PVC, installed between the deadmen sheetpiles and the front face sheet piles, and grouted. Signal wires were zip-tied to the tie-rod bar and routed to the sheet pile face. Figure A-2 shows the manufacturer cut sheet for these instruments, and Photograph A-4 shows the strain gages after being installed on the tie-rod.

A.3 CRACKMETERS

We used Geokon Model 4420 vibrating wire displacement transducers (crackmeters) with 2-inch range for monitoring displacement of the abutment seat relative to the coping. Figure A-3 shows the manufacturer cut sheet for these instruments. Each instrument included 1/4–inch-diameter

PVC signal cable that was routed through the conduit run leading to the appropriate multiplexer box.

One horizontal and vertical crackmeter were installed at both Instrument Line I1 and I2. The crackmeters were affixed to the coping and abutment seat using adhesive anchors. 1/2-inch diameter holes were predrilled to a depth of approximately 3 inches for each of the anchor ends of the crackmeter. A two part anchoring epoxy was used to secure the 3/8-inch diameter anchor into the predrilled holes. Photograph A-5 shows the horizontal and vertical crackmeters installed on the coping and abutment seat.

A.4 SHAPEACCELARRAY

We used Measurand's ShapeAccelArray (SAA) to measure lateral deflection of the sheet pile wall at Instrument Line 1 (I1). The SAA is an embedded in-place inclinometer system that provides near continuous readings using accelerometers. The SAA consists of rigid segments connected by sensorized joints containing microelectromechanical system (MEMS) accelerometers to measure the tilt from the Z axis. Figure A-4 shows the manufacturer cut sheet for these instruments.

A 3-inch diameter steel pipe was welded to the corner of the sheet pile to provide an access pipe for the SAA system. An angled steel shoe was welded at the base of the steel pipe for protection during sheet pile driving. After the compacted backfill was completed to the top of the sheet pile the SAA was installed within a 1-inch diameter electrical PVC conduit and placed inside the steel pipe. A cement-bentonite grout mix was poured inside the steel pipe around the PVC to secure the SAA to the wall. The x-direction of the SAA is perpendicular to the sheet pile face, and the y-direction is parallel to the sheet pile face. Photograph A-7 shows the 3-inch diameter pipe installed on the sheet pile.

A.5 TENCATE GEODETECT

Tencate GeoDetect fiber optic strain fabric was used for strain measurement in Abutment 4. GeoDetect is a geosynthetic with fiber optic sensing technologies embedded within the fabric. Figure A-5 shows the manufacturer cut sheet for the GeoDetect fiber optic sensing geosynthetic.

Tencate GeoDetect Fiber Optic Strain was utilized in instrument lines I1 through I3. GeoDetect is an integrated fiber optic fabric that allows for the measurement of strain within the compacted soil structure. The GeoDetect strips were placed on a thin layer of sand after the compaction of the previous lift. After the GeoDetect strips were placed the next geosythnetic fabric layer was placed over the GeoDetect strip. Certain GeoDetect strips were folded to concentrate the fiber optic sensors near the sheet pile face. A minimum of 6 inches of loose fill was placed over the geosynthetic fabric prior to running heavy machinery over the GeoDetect strip. Photograph A-7 show the installation of a GeoDetect strain strip.

A.6 FOIL RESISTANCE STRAIN GAGE FABRIC

Foil resistance strain gages were used for strain measurement in Wall DH. Photograph A-8 shows the strain gage instrumented fabric during installation.

Prior to the application of the strain gages, 10-foot wide by 10-foot long sections of the geosynthetic fabric was obtained from the contractor. High elongation strain gages, Tokyo Sokki Kenkyujo Type YFLA-20, were installed on the fabric in our laboratory, prior to construction of the wall. The strain gages are 20 mm in length and have a 120 ohm gage resistance. The gages were secured to the fabric using DOW 5641354 epoxy. Two strain gages were installed at each location for redundancy. Lead wires were soldered to each gage, zip tied to the fabric for strain relief, and then the connections were sealed with epoxy. The instrumented fabric was then supported with plywood to keep the strain locations rigid during storage and transportation prior to installation.

3500, 4800 Series

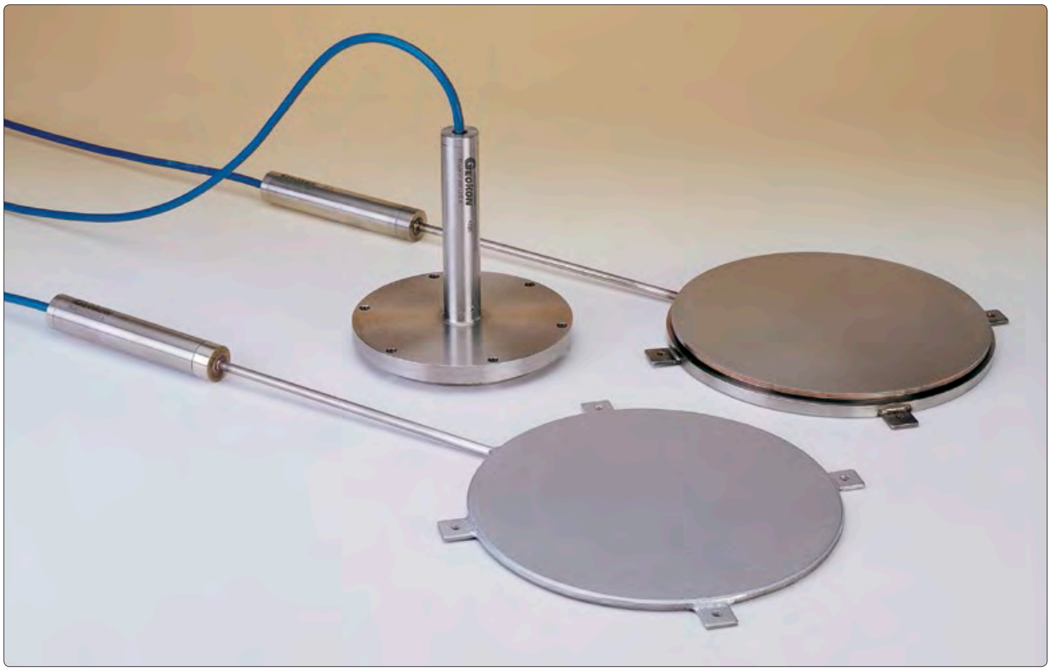
Earth Pressure Cells

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.

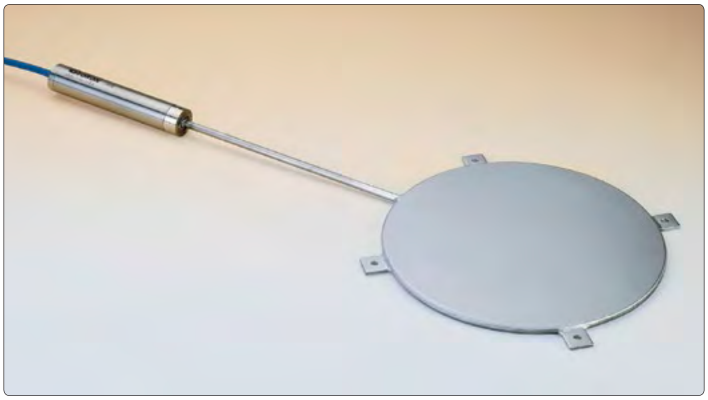
Advantages & Limitations

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.

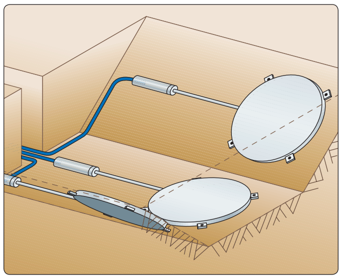
Typical of all closed hydraulic systems, earth pressure cells are sensitive to temperature changes which cause the internal fluid to expand at a different rate than the surrounding soil giving rise to spurious fluid pressure changes. The magnitude of the effect depends to a greater extent on the elasticity 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



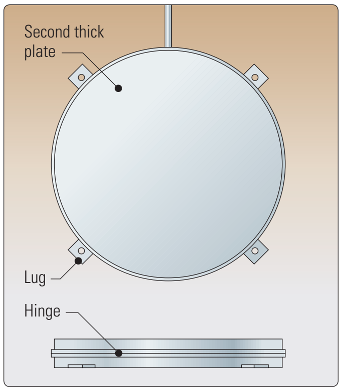
Model 4800 Earth Pressure Cell.

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.

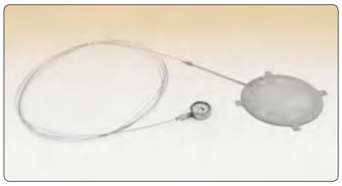


Model 4800 Earth Pressure Cells installed in fill for soil pressure measurement in three directions.

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.



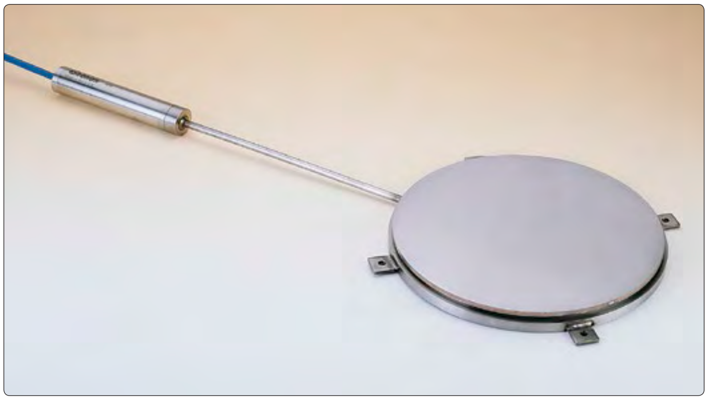
Model 4815 pressure cell, with two thick plates, for use in granular materials.



Model 4800 Earth Pressure Cell with a Bourdon Tube Pressure Gauge.

Models 4800, 4810 and 4815 are also available with a Bourdon Tube Pressure Gauge (2½" dial) in place of the vibrating wire pressure transducer. The pressure gauge is liquid-filled and features 316 stainless steel wetted parts, a 304 stainless steel case and crimp ring. Available in pressure ranges up to 15,000 psi (103 MPa) (1.5% span accuracy).

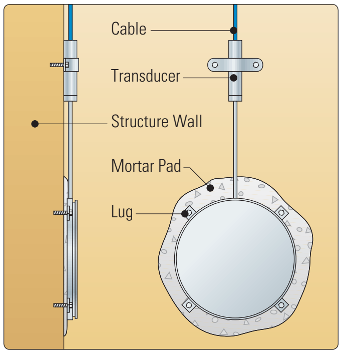
Model 4810 Contact Pressure Cells



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

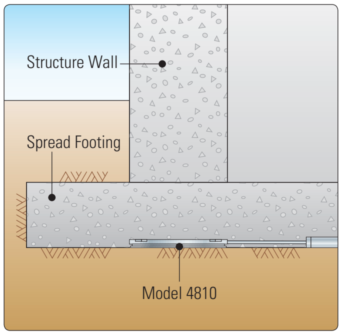
The Model 4810 Contact Pressure Cell is designed to measure soil pressures on structures. The backplate of the cell which bears against the external surface of the structure is thick enough to prevent the cell from warping. The other plate is thin and is welded to the backplate in a manner which creates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

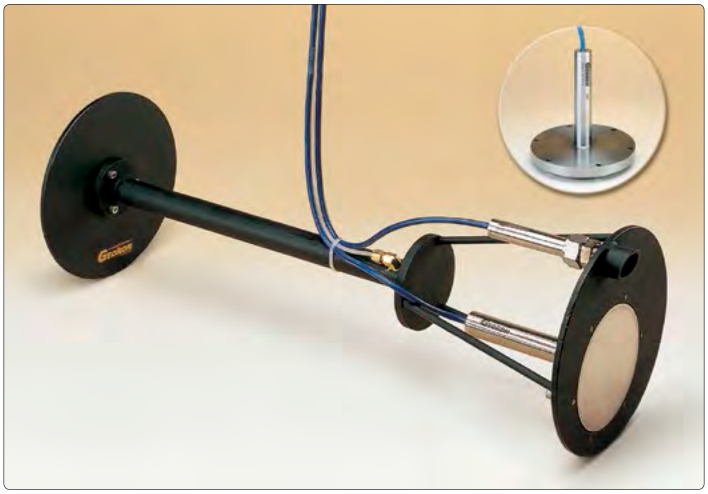
Cells installed at the base of slabs and footings to measure bearing loads should always be positioned inside the concrete with the sensitive face pressed against the compacted fill. Cells placed in the fill below the concrete often become decoupled from the soil pressure due to the impossibility of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



Model 4810 installation in a spread footing.

FIG. A-1
Sheet (2 of 4)

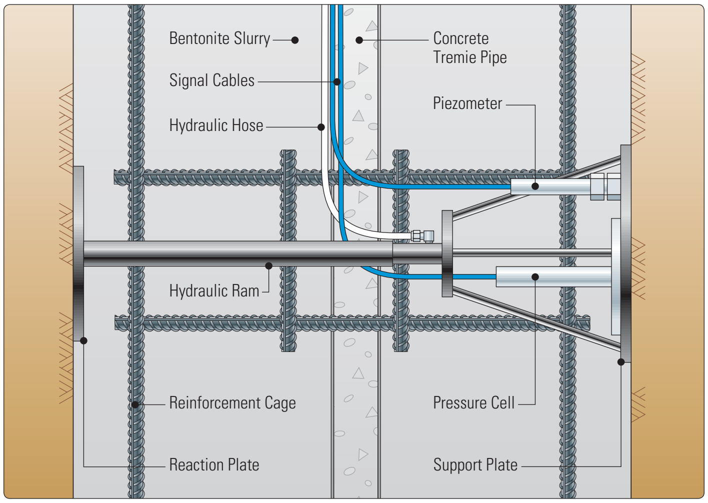
Model 4820 Jackout Pressure Cells



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.



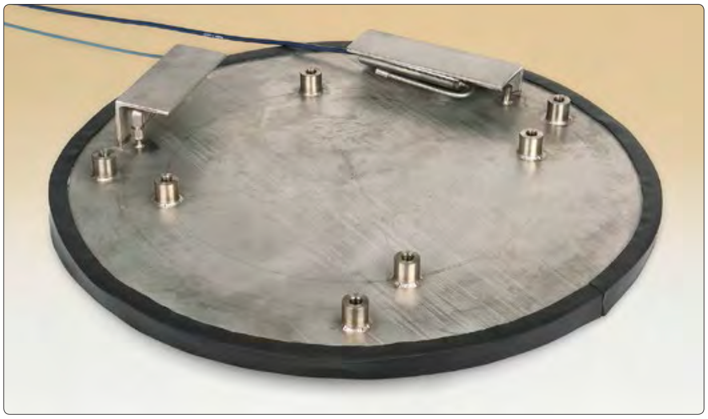
Jackout Pressure Cell assembly installed in diaphragm wall.

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).

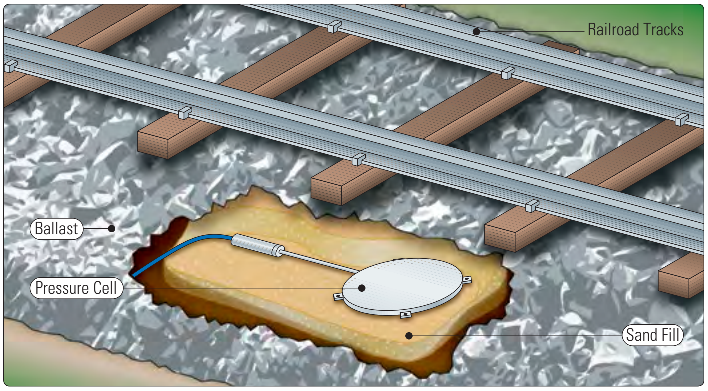
Model 4855 Pile Tip Pressure Cell



Model 4855 Pile Tip Pressure Cell.

The Model 4855 Pile Tip Pressure Cell is used to measure pile-tip loads in cast-in-place concrete piles (caissons). Like the Model 4810, the Pile Tip Pressure 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	2, 3, 5, 7.5, 10, 20 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	50 × 600 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	316 Stainless Steel	316 Stainless Steel	316 Stainless Steel	316 Stainless Steel	316 Stainless Steel	316 Stainless Steel	316 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] *Stated accuracy is for the pressure transducer alone. The total system accuracy (pressure transducer + pressure cell) is subject to site-specific variables.*

[3] *Other sizes available on request.*

FIG. A-1
Sheet (4 of 4)

Spot-Weldable Strain Gages

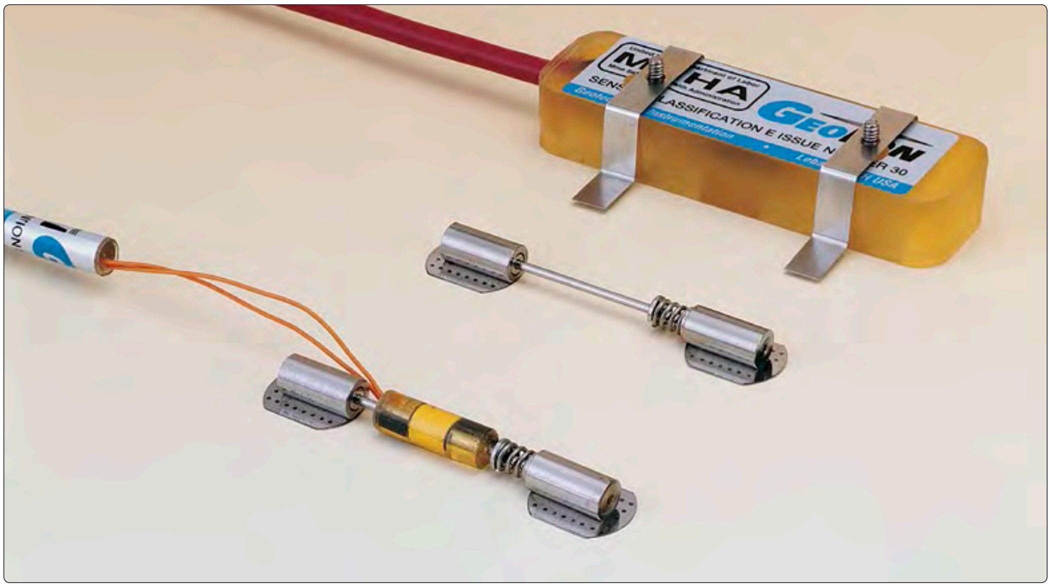
Applications

The 4100 Series Vibrating Wire Strain gages are designed to measure strains in or on…

- **Pipelines**
- **Bridges**
- **Buildings**
- **Tunnel linings**
- **Piles**
- **Reinforcement bars**

Model 4150 shown with optional arc-weldable mounting blocks.

Model 4151 Strain Gage mounted to a fiberglass rebar.



Model 4150 (front) and Model 4100 Spot-Weldable Strain Gages.

Operating Principle

The Model 4100 and 4150 Vibrating Wire Strain Gages are designed primarily to measure strains on the surface of steel structures, although they may also be used to measure strains in other materials. Essentially, the gages consist of a steel wire tensioned between two mounting blocks. These blocks are attached to stainless steel shim-stock tabs, which can be either spot-welded or epoxy bonded to the surface in question. Also available is the Model 4151 Strain Gage with groutable pins welded to the end-blocks.

Deformation of the structure under load causes the end blocks to move relative to one another resulting in a change in the wire tension and a corresponding change in the fundamental, resonant frequency of vibration of the wire.

The wire is plucked by means of an electronic coil and permanent magnet connected by a signal cable to a readout, which sends voltage pulses to the coil. The vibration of the wire so produced induces an alternating current in the coil—the frequency of which is the same as the vibrational frequency of the wire and is measured using the same electronic coil and a readout. The frequency value is squared and multiplied by a constant so that the values displayed by the readout are directly in microstrain.

Advantages and Limitations

The Model 4100 and 4150 strain gages are small so that they can be used in confined spaces. They are particularly useful for spot-welding to steel reinforcement bars and rock bolts and for spot welding to pipelines and other sensitive structures where arc welding is prohibited, or where the services of an arc welder are unavailable.

All components are made from stainless steel for corrosion protection and the gages are waterproof.

The Model 4100 and 4150 enjoy all the advantages of vibrating wire sensors: i.e., excellent long term stability, maximum resistance to the effects of water and a frequency output suitable for transmission over very long cables.

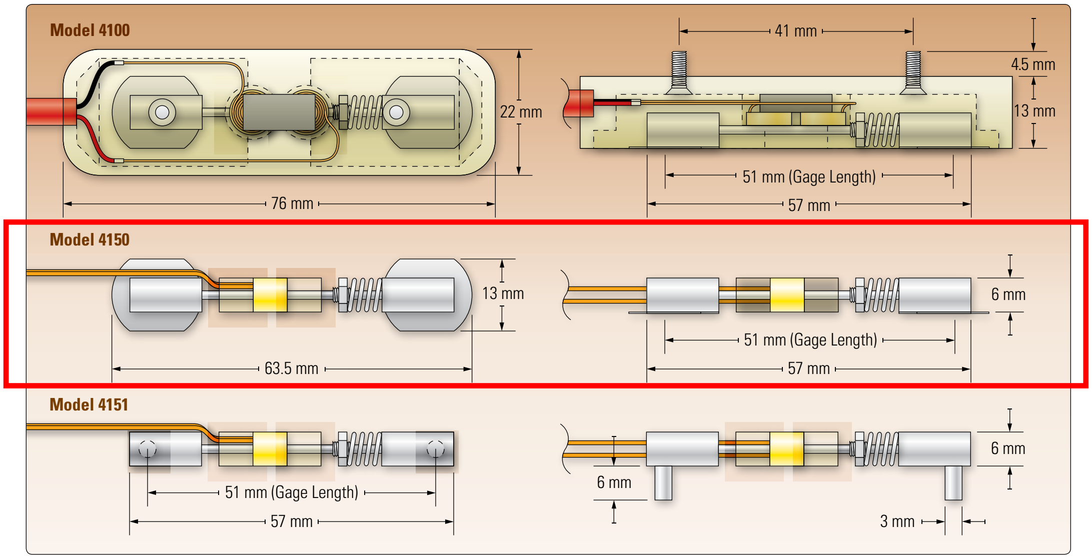
Each gage also incorporates a thermistor so that the temperature can be read and displayed by the readout.

An external spring holds the wire in initial tension thus greatly simplifying the installation procedure.

Gages are certified by MSHA for use in explosive atmospheres when used with certified readouts.

FIG. A-2
Sheet (1 of 2)

● *Model 4150 under the Model 4150-1 protective cover plate, with dimensions.*



● *Dimensions of the Models 4100, 4150 and 4151 strain gages.*

System Components

The Model 4100 consists of two main components: the gage itself and a separate plucking coil housing. The stainless steel tube around the wire is O-ring sealed so that the gages are waterproof. This tube floats free and thus does not impede the free movement of the end blocks. The coil housing contains a thermistor and fits loosely over the gage. It is secured in place by means of stainless steel straps. It also serves as a measure of protection from mechanical damage.

The model 4150 consists of only one component since the coil housing is encapsulated around the stainless steel tube that protects the wire. The Instrument cable is connected to the coil housing through small diameter lead wires. A thermistor, contained in a small encapsulation, is provided at the end of the cable. A separate cover plate protects the gage from mechanical damage. Stainless steel straps hold the cable and cover plate firmly to the structure.

The model 4151 is a modification of the 4150 strain gage in which the spot-weldable tabs have been replaced by pins welded to the end blocks and designed to be grouted into two short holes drilled into the material under test. Special versions of the 4151 are available with extended ranges: 5,000 με (4151-1) and 10,000 με (4151-2). These gages are particularly useful for measurements in high strain regimes such as on plastic pipes or piles and on fiberglass structural members and rebars.

Accessories include setting tools, capacitive discharge welder (for spot welding) and epoxy kits (for bonded applications).

Technical Specifications

	4100	4150	4151	4151-1	4151-2
Standard Range	3000 με	3000 με	3000 με	5,000 με	10,000 με
Resolution	0.4 με	0.4 με	0.4 με	1.0 με	2.0 με
Accuracy¹	±0.5% F.S.	±0.5% F.S.	±0.5% F.S.	±0.5% F.S.	±0.5% F.S.
Nonlinearity	< 0.5% F.S.	< 0.5% F.S.	< 0.5% F.S.	< 0.5% F.S.	< 0.5% F.S.
Temperature Range²	−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
Active Gage Length	51 mm	51 mm	51 mm	51 mm	51 mm

¹±0.5% F.S. with standard batch calibration. ±0.1% F.S. with individual calibration. Accuracy established under laboratory conditions.
²Other ranges available on request.

FIG. A-2
Sheet (2 of 2)

The World Leader in Vibrating Wire Technology™

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| *Doc. Rev. G.5, 06/14*

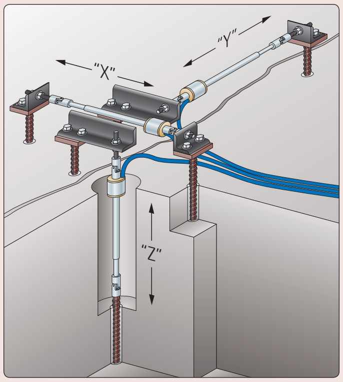
4400 Series

Vibrating Wire Displacement Transducers

Applications

The 4400 Series are designed to measure or monitor the…

- **Expansion or contraction of a joint**
- **Strains in tendons and steel cables**
- **Movement across surface cracks and joints**
- **Closures in underground excavations, tunnels, etc.**
- **Displacements associated with landslides**
- **Movement of boulders, snow, etc. on unstable slopes**



- *Three Model 4420 Crackmeters configured as a single 3-D Crackmeter.*

- *Model 4420-3 Low Profile Crackmeter for measurements in the "Z"direction.*

- *Model 4410 Strandmeter (front), Model 4400 Embedment Jointmeter (center) and Model 4420 Crackmeter (rear).*

Operating Principle

Geokon vibrating wire displacement transducers are designed to measure displacements across joints and cracks in concrete, rock, soil and structural members.

In essence, the transducer consists of a vibrating wire in series with a tension spring. Displacements are accommodated by a stretching of the tension spring, which produces a commensurate increase in wire tension.

The wire and spring are connected to a free-sliding rod which protrudes from, and is free to slide inside, a protective outer tube. An O-ring seal prevents water from entering.

The frequency signal is transmitted through the cable to the readout location, conditioned, and displayed on portable readouts or dataloggers.

Advantages and Limitations

The 4400 Series Displacement Transducers are fabricated entirely from stainless steel and are waterproof to 1.75 MPa, which, coupled with their excellent long-term stability, guarantees reliability and performance in even the harshest environments.

An advantage of vibrating wire displacement transducers over more conventional linear potentiometers (or LVDT's) lies mainly in the use of a frequency, rather than a voltage, as the output signal. Frequencies may be transmitted over long lengths of electrical cable without appreciable degradation caused by variations in cable resistance or leakage to ground. This allows for a readout location that may be over a thousand meters from the transducer.

Thermistors are provided with all transducers for temperature measurement.

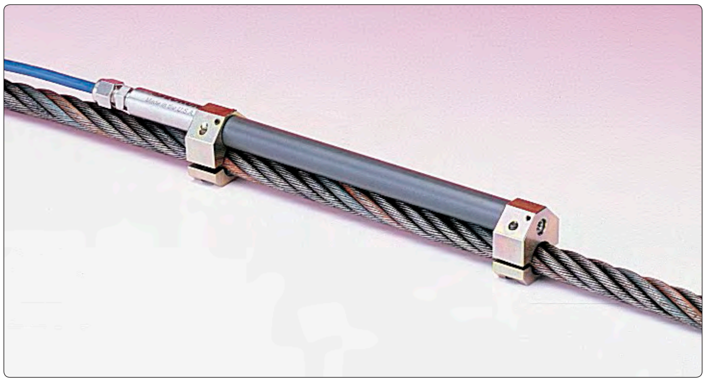
Model 4400 Embedment Jointmeter

- *Model 4400 Embedment Jointmeter shown with socket removed.*

The Model 4400 is designed for use in construction joints; e.g. between lifts in concrete dams. In use, a socket is placed in the first lift of concrete and, when the forms are removed, a protective plug is pulled from the socket. The gage is then screwed into the socket, extended slightly and then concreted into the next lift. Any opening of the joint is then measured by the gage which is firmly anchored in each lift. The sensing gage itself, is smaller than the protective housing, and a degree of shearing motion is allowed for by the use of ball-joint connections on the gage.

A tripolar plasma surge arrestor is located inside the housing and provides protection from electrical transients such as those that may be induced by lightning.

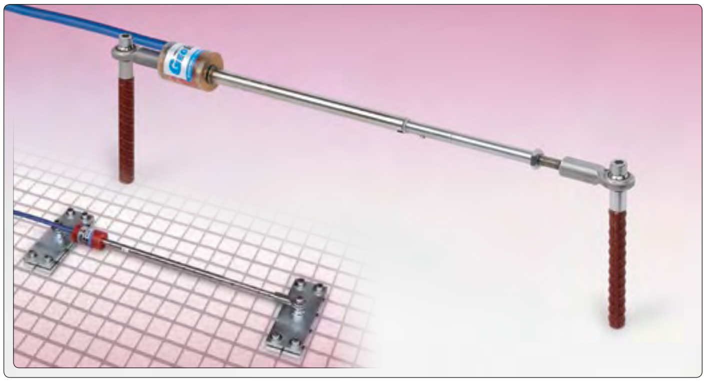
Model 4410 Strandmeter



- *Model 4410 Strandmeter.*

The Model 4410 Strandmeter is designed to measure strains in tendons and steel cables, including bridge tendons, cable stays, ground anchors, tiebacks, etc. Two clamps at each end of the strandmeter hold it firmly onto the cable. Various size clamps are available.

Model 4420 Crackmeter



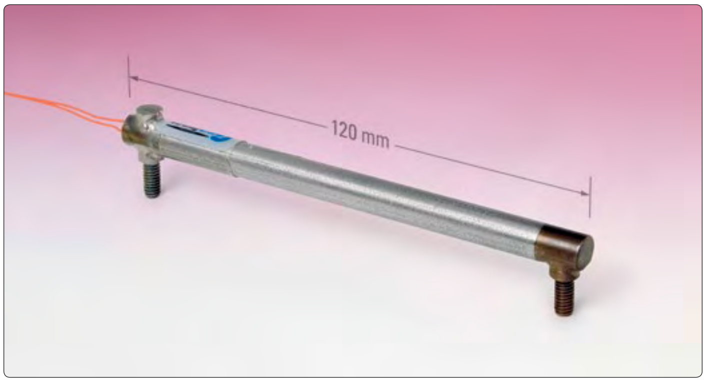
- *Model 4420 Crackmeter (inset: configured with special clamps for attachment to geogrids).*

The Model 4420 Crackmeters are designed to measure movement across joints such as construction joints in buildings, bridges, pipelines, dams, etc.; tension cracks and joints in rock and concrete.

The ends of the sensor are attached to anchors (with ball joints) that have been grouted, bolted, welded or bonded on opposite sides of the crack or fissure to be monitored. 3-D mounting brackets, which allow measurement of displacements in three orthogonal directions, and special clamps for attachment to a variety of earth reinforcements and geogrids, are also available.

Special versions of the Model 4420 are offered including low profile models (Model 4420-3); versions for underwater use, where water pressures exceed 1.7 MPa; and versions for use in cryogenic or elevated temperature regimes (please contact Geokon, Inc. for details).

Model 4422 Micro Crackmeter

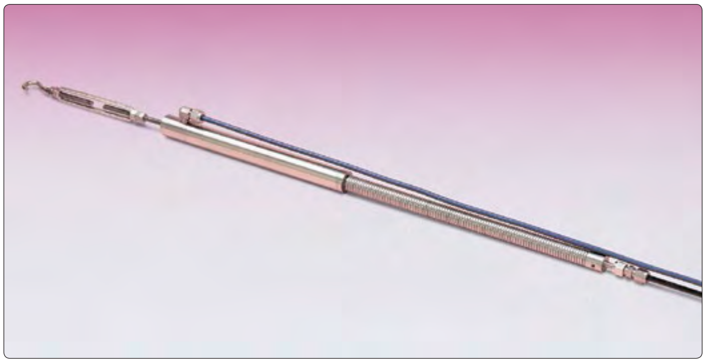


- *Model 4422 Micro Crackmeter.*

The Model 4422 is a miniature crackmeter intended to measure displacements across surface cracks and joints. It has been specially designed for applications where access is limited and/or where monitoring instrumentation is to be as unobtrusive as possible (e.g. on historical structures or buildings).

FIG. A-3
Sheet (2 of 4)

Model 4425 Convergence Meter



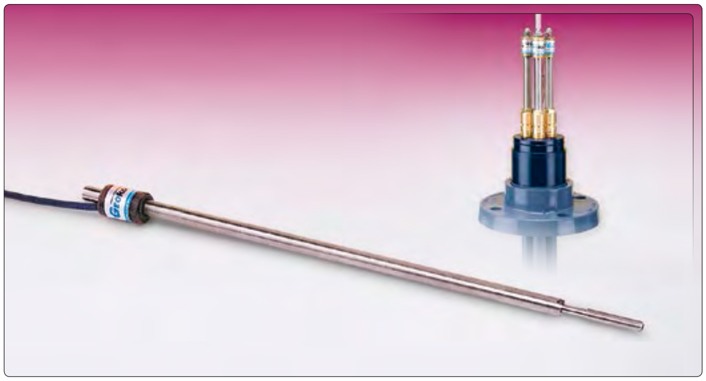
● *Model 4425 Convergence Meter.*

The Model 4425 Convergence Meter is designed to detect deformation in tunnels and underground caverns by measuring the contraction (or elongation) between 2 anchor points fixed in the walls of the tunnel or cavern.

The Model 4425 consists of a spring-tensioned vibrating wire transducer assembly, turnbuckle, 6 mm diameter connecting rods (stainless steel, fiberglass or graphite), rod clamp, and a pair of anchor points. Changes in distance between the 2 anchors are conveyed by the connecting rods and measured by the transducer.

The Model 4425 can operate in horizontal, inclined or vertical orientations. In areas where construction traffic is expected or where the instrument may be left in an exposed location, some form of protective housing should be considered.

Model 4450 Displacement Transducer



● *Model 4450 Displacement Transducer and Extensometer Head Assembly (inset).*

The Model 4450 Displacement Transducer provides remote readout capability for Borehole Extensometers (see the Model A-3, A-4, A-5, A-6 Rod-Type Borehole Extensometers data sheet for more information). They are particularly useful where other types of vibrating wire sensors are used and/or for installations where long cable runs are required.

The Model 4450 can also be installed between borehole anchors, in conjunction with the requisite length connecting rod, to provide a permanent, in-place incremental extensometer (contact Geokon for details).

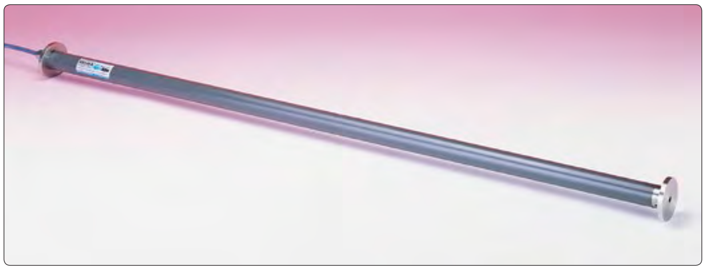
Model 4427 Long-Range Displacement Meter

● *Model 4427 Long-Range Displacement Meter.*

The Model 4427 Long-Range Displacement Meter is ideally suited for the measurement of large displacements associated with landslides. The Model 4427 can also be used for monitoring the movement of boulders, snow, etc., on unstable slopes.

The Model 4427 consists of a vibrating wire displacement transducer coupled to a spring motor drive by means of a lead screw. As the cable is pulled, the motor drum rotates and advances the lead screw. Thus the rotation is converted into a linear displacement which is measured by the vibrating wire displacement transducer.

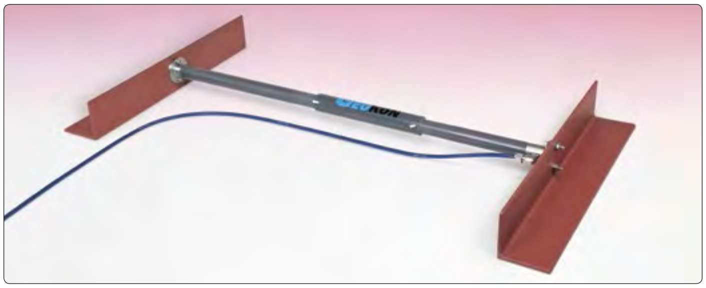
Model 4430 Deformation Meter



● *Model 4430 Deformation Meter.*

Specifications overleaf: For full description, please see the Model 4430 Deformation Meter data sheet.

Model 4435 Soil Extensometer



● *Model 4435 Soil Extensometer.*

Specifications overleaf: For full description, please see the Model 4435 Soil Extensometer data sheet.

FIG. A-3
Sheet (3 of 4)

Technical Specifications

Model	Standard Ranges	Resolution	Accuracy[3]	Nonlinearity	Temperature Range[1]	Dimensions
4400 Embedment Jointmeter	12.5, 25, 50, 100 mm[1]	0.025% F.S.	±0.1% F.S.	< 0.5% F.S.	−20°C to +80°C	*Lengths:* 441, 441, 441, 569 mm *Diameter:* 51 mm *(flange)*
4410 Strandmeter	3 mm (15,000 με)[1]	< 5 με	±0.1% F.S.	< 0.5% F.S.	−20°C to +80°C	*Length:* 203 mm *Width:* 45 mm *(clamp)*
4420 Crackmeter	12.5, 25, 50, 100, 150 mm[1]	0.025% F.S.	±0.1% F.S.	< 0.5% F.S.	−20°C to +80°C	*Lengths*[5]*:* 318, 343, 397, 559, 649 mm *Diameter:* 8 mm *(shaft);* 25 mm *(coil)*
4420-3 Low Profile Crackmeter	25 mm[2]	0.01% F.S.	±1% F.S. (< ±0.25%F.S.)[4]	< 0.5% F.S.	−20°C to +80°C	*Dimensions (L × W × H):* 292 × 50 × 38 mm
4422 Micro Crackmeter	4 mm (±2 mm)	0.001 mm	±0.1% F.S.	< 0.5% F.S.	−20°C to +80°C	*Length:* 120 mm *Diameter:* 8 mm *(shaft)*
4425 Convergence Meter	12.5, 25, 50, 100, 150 mm[1]	0.025% F.S.	±0.1% F.S.	< 0.5% F.S.	−20°C to +80°C	*Lengths:* varies with application *Diameter:* 25 mm *(transducer)*
4427 Long-Range Displacement Meter	1, 2 m (without resetting)	0.025% F.S.	±1.0% F.S.	—	−30°C to +60°C	*Dimensions (L × W × H):* 610 × 152 × 152 mm *(enclosure)*
4430 Deformation Meter	25, 50, 100, 150, 300 mm[1]	0.025% F.S.	±1.0% F.S.	< 0.5% F.S.	−20°C to +80°C	*Length:* 1 m (standard); as required *Diameter:* 27 mm *(pipe);* 51 mm *(flange)*
4435 Soil Extensometer	25, 50, 100, 150, 300 mm[1]	0.025% F.S.	±1.0% F.S.	< 0.5% F.S.	−20°C to +80°C	*Length:* 610 mm *(minimum)* *Diameter:* 27 mm *(pipe);* 33 mm *(slip coupling)* *Dimensions (L × W × H):* 610 × 75 × 75 mm *(flange)*
4450 Displacement Transducer	12.5, 25, 50, 100, 150, 200, 230, 300 mm[1]	0.025% F.S.	±0.1% F.S.	< 0.5% F.S.	−20°C to +80°C	*Lengths*[6]*:* 187, 206, 272, 409, 474, 672, 698, 939 mm *Diameter:* 9.5 mm (12.5, 25, 50 mm ranges) 12.7 mm (100, 150, 200, 230, 300 mm ranges) *(tube);* 19 mm *(coil)*

---

[1] Other ranges available on request. | *[2] Other ranges (< 25mm) available on request.* | *[3] Accuracy established under laboratory conditions.* | *[4] Accuracy using polynomial.*

[5] Length dimensions are in mid-range position. | *[6] Length with shaft fully retracted.*

FIG. A-3
Sheet (4 of 4)

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The World Leader in Vibrating Wire Technology™

SAAF

Model 003

Description

The ShapeAccelArray Field (SAAF) is a type of SAA that is most commonly used. All SAA types 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 also be installed along the cross-section of tunnels and used in “mixed H/V” mode to measure convergence. Due to the bandwidth of the MEMS sensors and communication protocol, it is possible to use the SAAF to monitor 3D vibration data at up to three selected locations along the instrument. The SAAF model 003 has a non-multiplexed structure where every segment has a microprocessor unit and a temperature sensor.

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 SAA 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, SAA232-5, SAA Field Power 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)

FIG. A-4
Sheet (1 of 3)

Maximum number of segments:	200
Length of far tip end:	60 mm
Length of unsensorized near cable end:	340 mm (includes: Cable Terminator Segment underneath PEX, see diagram)
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 for 27 mm ID Conduit which allows for extraction:	3.5 m for SAAF500 2.0 m for SAAF305
Storage temperature:	-40°C to 60°C
Installation temperature[2]:	-5°C to 60°C
Operating temperature:	-35°C to 60°C polynomial temperature algorithm corrected
Waterproof to:	980 kPa
Power requirements:	12 VDC at 4.2 mA/segment

Dynamic Acceleration Measurements:

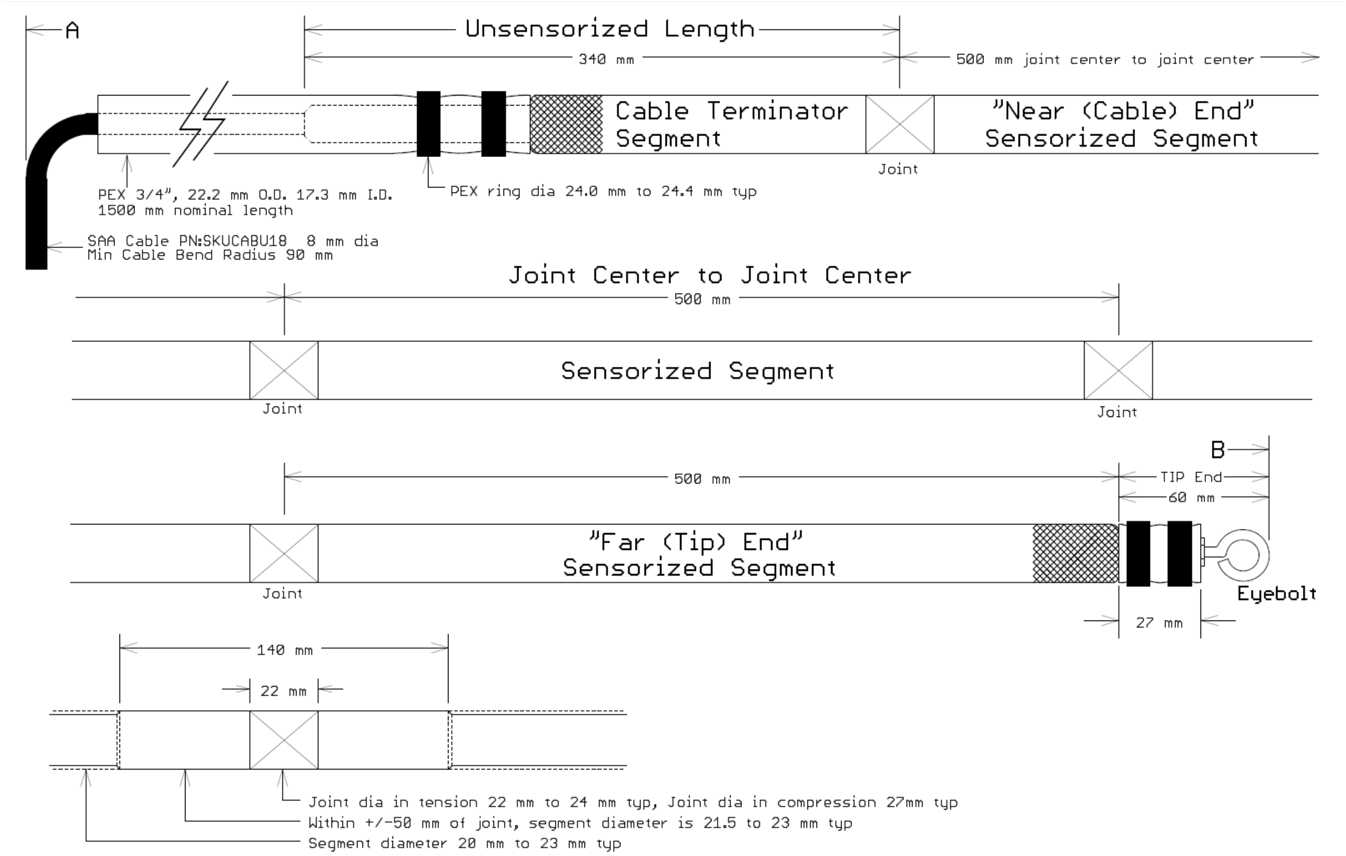
Range:	± 1.7 G
3dB Bandwidth:	50 Hz
Noise floor of MEMS:	110 $\mu G/Hz^{0.5}$
Data rate:	SAA232: 38.4 kbps to 230.4 kbps

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

FIG. A-4
Sheet (2 of 3)

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 SAAs 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.

TENCATE
GeoDetect®

TenCate GeoDetect®

Fiber Optic Sensing Geosynthetics

OUR COMPANY

TenCate develops and produces materials that function to increase performance, reduce costs and deliver measurable results by working with our customers to provide advanced solutions.

OUR PRODUCT

The use of fiber optics in structural health monitoring systems for civil engineering applications have been widely used for many years. By integrating fiber optic sensing into a geosynthetic, TenCate GeoDetect® is the first system designed specifically for geotechnical applications. The TenCate GeoDetect® solution embodies a geocomposite fabric, fiber optics, software and instrumentation to provide an innovative solution for the multifunctional requirements of a geotechnical application e.g. in-plane drainage capability, anchoring interface with the soil, protection of the optical fiber, reinforcement, separation and filtration in addition to data capture. It combines the benefits of geosynthetic materials with the latest sensing and measurement technologies to provide owners with unique information that drives risk reduction and, in some cases, cost reduction. TenCate GeoDetect® is a customizable solution created to meet the unique requirements of each project. Fiber Bragg Gratings (FBG), Brillouin scattering and Raman scattering are all proven fiber optic technologies that can be built into TenCate GeoDetect®. These technologies measure strain, strain & temperature or temperature only changes in soil structures.

Strain as low as 0.02% can be measured with a spatial resolution of 0.5 m. With the proper software, changes in temperature can be monitored at 0.1 C° with a spatial resolution of 1.0 m.

TenCate GeoDetect® can be used for long term monitoring, early warning system or short term performance evaluation. Continuous full time remote monitoring can transmit real time data for review and analysis. Project tolerances can be selected for early warning systems to be activated. Monitoring equipment can be accessed remotely or manually at the site depending on the needs of the project. TenCate GeoDetect® can be customized to fit the needs of your project.

TenCate GeoDetect® is an Innovation that Provides:

- Assurance the design materials are meeting or exceeding expected factors of performance.
- Early warning indication of changes in material performance or local conditions that were not expected, e.g. high strains, subsidence, voids, etc.
- A customized solution that will provide the owner with increased operating safety margin on certain demanding soil reinforcement applications, e.g. walls, steep slopes, embankments, levees, foundations, soft soils and subsidence (karst or mine) regions. This information can be used to lower long-term liability.
- More effective means of monitoring geosynthetic materials and soil structures in demanding applications, leading to better land use, and lower overall project costs.
- A positive impact on sustainability with lower risk and longer lasting structures due to its ability to monitor appropriate performance.

OUR APPLICATIONS

The TenCate GeoDetect® solution is ideal for:

- Walls
- Embankments
- Slopes
- Levees
- Roads/Rails
- Landfills
- Pipelines

OUR SERVICE

TenCate offers complete technical assistance. Our comprehensive service includes assistance during design, specification and throughout the process. TenCate makes the difference.

Protective Fabrics
Space Composites
Aerospace Composites
Advanced Armour

Geosynthetics
Industrial Fabrics
Grass

TENCATE
materials that make a difference

FIG. A-5
Sheet (1 of 2)

TENCATE
GeoDetect®

TenCate GeoDetect®

Fiber Optic Sensing Geosynthetics

TenCate GeoDetect® Fiber Optic

TECHNICAL DATA

Fiber Optic	Units	FBG	BR
Minimum diameter	mm	0.9	2
Minimum strain detection	%	0.02	0.02
Connection to the textile		Knitting yarn	Knitting yarn

TenCate GeoDetect® S Composite Strip	Test Method	Units		35	95	230
Tensile strength	EN ISO 10319	kN/m	MD/CD	37/12	100/12	242/12
Elongation at maximum strength	EN ISO 10319	%	MD/CD	11.5/85	11.5/85	11.5/95
Tensile strength at 2% strain	EN ISO 10319	kN/m	MD	7.5	20	46
Tensile strength at 5% strain	EN ISO 10319	KN/m	MD	14	40.4	84.7
Friction properties in contact with sand (:40°)	EN ISO 12957-1	degrees		30°	30°	30°
Puncture resistance (CBR)	EN ISO 12236	kN		2.4	3.4	4.9
In the plane water flow capacity @ 20 kPa	EN ISO 12958	m3/s/m		$20\ 10^{-7}$	$20\ 10^{-7}$	$20\ 10^{-7}$
Weight per unit area (without optical cables)		g/m²		290	400	620
Standard width (Other width on demand)[1]		m		5.3	5.3	5.3
Standard Length(on demand)[1]		m		100-600	100-600	100-600

MD: Machine Direction, also direction of the optical cables
CD: Cross Direction
(1) Custom roll sizes available

The values given are average values obtained in our laboratory and in accredited testing institutes. The information given in this datasheet is to the best of our knowledge true and correct. However new research results and practical experience can make revision necessary. The right is reserved to make changes without notice at any time. No guarantee or liability can be drawn from the information mentioned herein.

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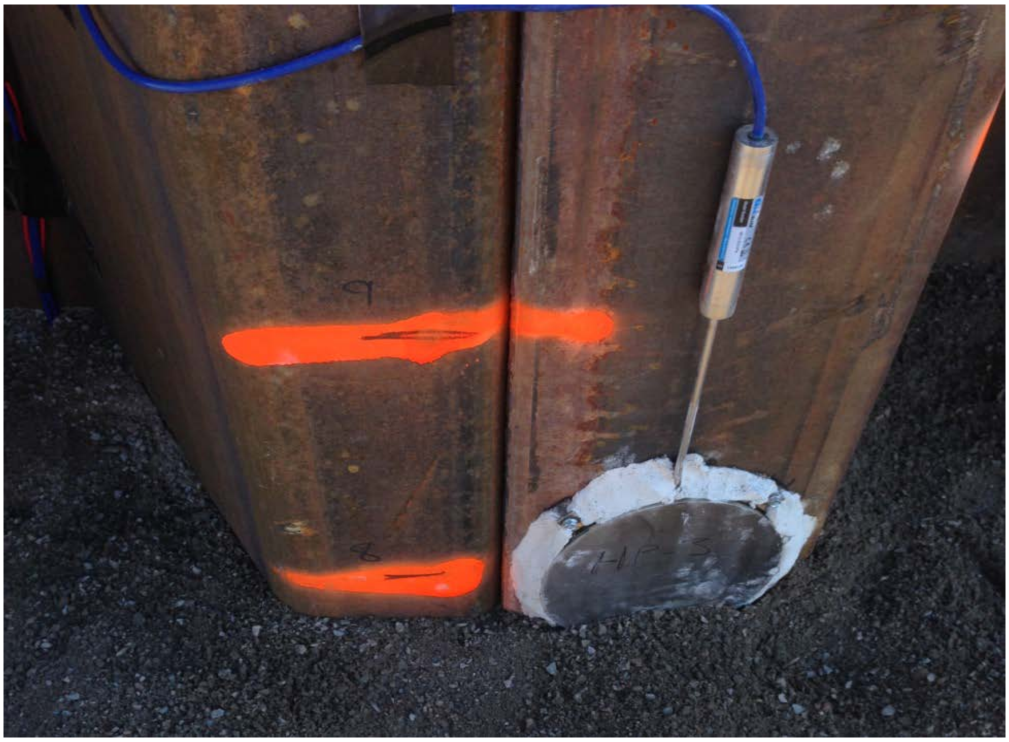

Photograph A-1. Horizontal earth pressure cell install on sheet pile.

Photograph A-2. Horizontal earth pressure cell install on masonry block.

CDOT GRS Instrumentation
I-70 Over Smith Road
Aurora, Colorado

INSTRUMENT PHOTOGRAPHS

February 2016 23-1-01395-001

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Geotechnical and Environmental Consultants

FIG. A-6
Sheet 1 of 4

Photograph A-3. Installation of vertical earth pressure cells.

Photograph A-4. Tie-Rod Strain Gage.

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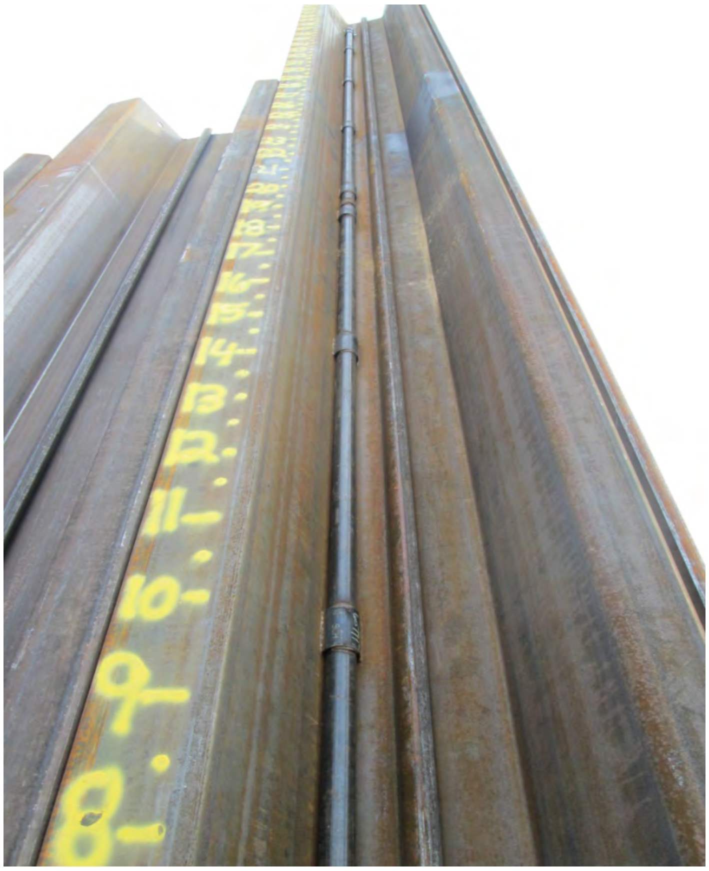
FIG. A-6
Sheet 2 of 4

Photograph A-5. Horizontal and vertical crackmeters.



Photograph A-7. 3-inch diameter pipe installed on sheet pile.

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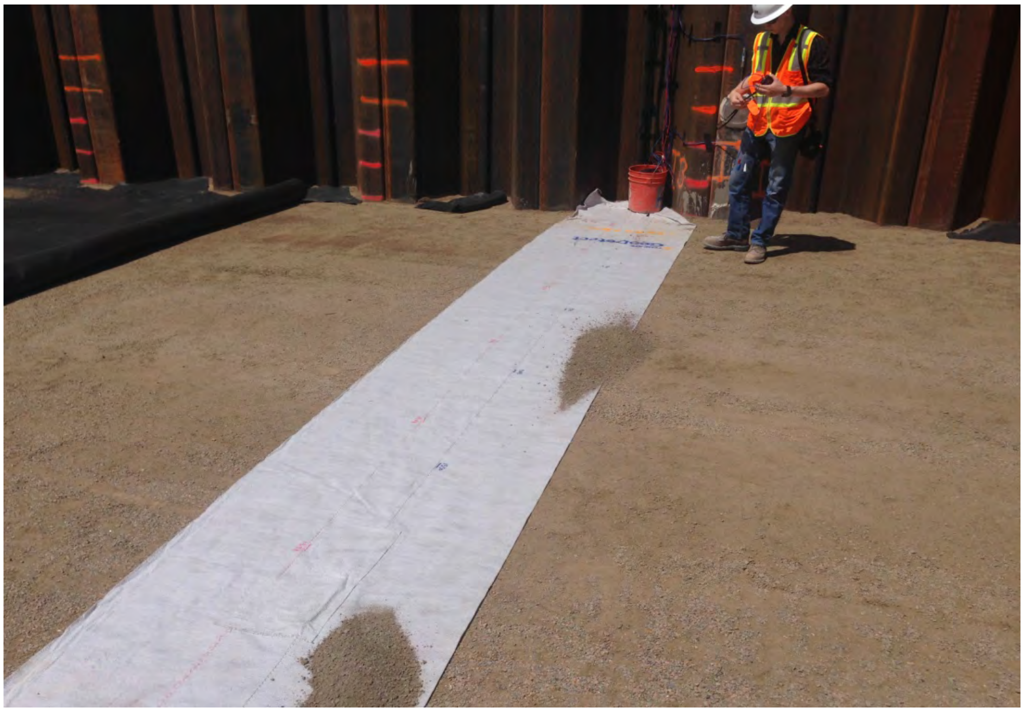
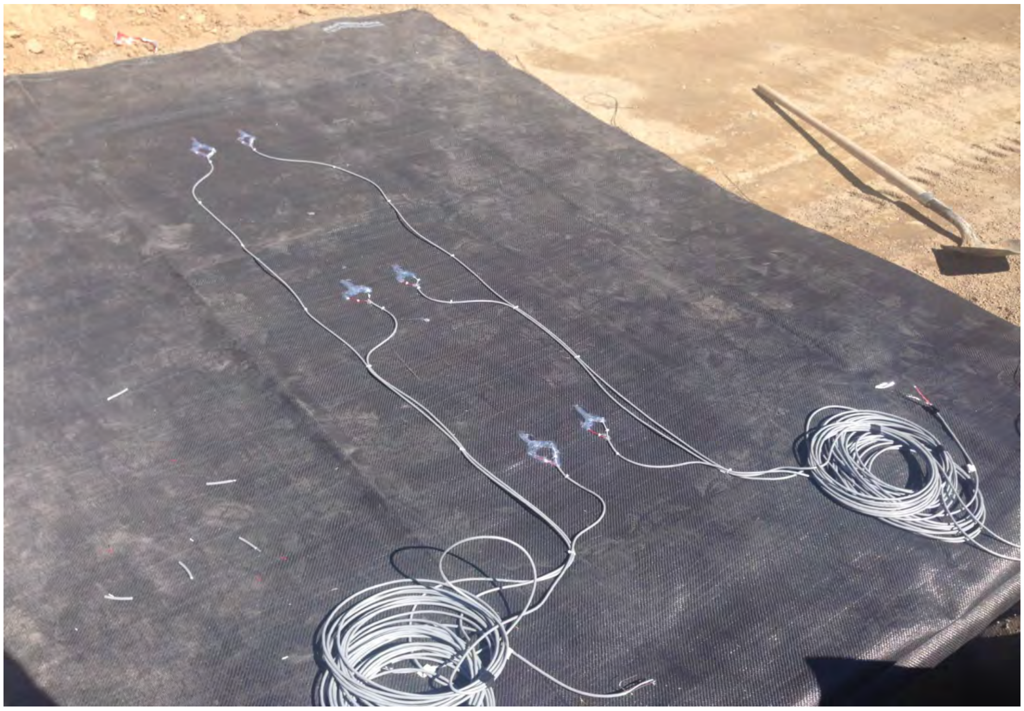
FIG. A-6
Sheet 3 of 4



Photograph A-7. Installation of GeoDetect Fiber Optic Strips.



Photograph A-8. Installation of strain gage instrumented fabric.

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FIG. A-6
Sheet 4 of 4

APPENDIX B – AUTOMATED DATA ACQUISITION SYSTEM

TABLE OF CONTENTS

Page

FIGURES

APPENDIX B – AUTOMATED DATA ACQUISITION SYSTEM

B.1 INTRODUCTION

Relatively continuous monitoring of the instrumentation at this project site is provided by the use of Campbell Scientific dataloggers and associated measurement components for vibrating wire instruments and a Micron Optics interrogator for fiber optic strain measurements. We designed the monitoring systems to provide remotely accessible data logging capabilities. Each data logger is powered by batteries that are recharged with solar panel units. Remote data acquisition of each data logger is enabled by Raven XT modems. Cut sheets of all listed components used are provided as Figures B-1 through B-7. Sample figures of graphs of the automated output are presented as Photographs B-9 and B-10.

B.2 ABUTMENT 4 VIBRATING WIRE DATA LOGGER

The Abutment 4 vibrating wire data logger system incorporated five remote multiplexers hard-wired together through a daisy chain configuration. The components used in the Abutment 4 vibrating wire data logger system are shown installed in Photograph B-1 through B-4, and included:

- Campbell Scientific CR1000 Datalogger
- Campbell Scientific CR800 Datalogger
- Campbell Scientific BP12 12V 12 Amp-hour Battery
- Campbell Scientific AVW200 Vibrating Wire Interface
- SAA 232 Interface
- Campbell Scientific SC32B RS-232 Interface
- SunSaver Solar Controller (power regulator)
- 40 watt Solar Panel
- Geokon Model 8032 Multiplexer (in each multiplexer enclosure)
- Geokon Model 4580 Barometer

The signal leads from Instrument Lines 1 and 2 were routed through both the coping and girder diaphragm concrete within rigid electrical PVC conduit, to the appropriate multiplexer enclosure, and connected to the appropriate channels of the multiplexer. Instrument Line 3 signal leads were routed along the backside of the eastbound sheetpile wall and then through the sheetpile at the westbound wall. The leads were then routed into a multiplexer installed along the top of the coping. Multiconductor cables were then routed from the daisy-chained multiplexers to the data logger through 2-inch PVC conduit along the top of the coping to the Abutment 4 data logger location. The data logger box is mounted on the sloped coping at the southeast corner of Abutment 4. The solar panel and antenna are mounted to a pole that is fixed to the coping and embedded in the backfill of the rip-rap channel adjacent to the coping. Access pull-boxes were installed along the length of the conduit leading to the data logger. An access hole was drilled in the data logger enclosure for routing and securing the conduit.

B.3 ABUTMENT 4 FIBER OPTIC DATA LOGGER

The fiber optic data logger was installed at the base of the slope of the southeast corner of Abutment 4. The data logger is installed on two metal poles embedded in concrete with a metal cabinet data logger box, solar panels and external battery box affixed to the poles. The Abutment 4 Fiber Optic Data Logger components included:

- Micron Optics SM225 Static Optical Sensing Interrogator
- Morningstar ProStar-30 Solar Charge Controller
- 3 ea 140 watt Solar Panels
- 3 ea deep cycle 110-ah 12 volt Batteries

Photographs of the data logger components and data logger setup are shown in Photographs B-5 and B-6. The fiber optic signal wires were routed through the same 2-inch conduit used for the Abutment 4 vibrating wire data logger. A junction box allowed the fiber optic leads to continue routing to the fiber optic data logger located approximately 50 feet southeast of the Abutment 4 coping. At the end of the coping the conduit is buried approximately 12 inches below the ground surface and routed to the data logger location. The metal data logger enclosure is mounted on two galvanized steel poles embedded within concrete. The top of the solar panels are secured to the poles with the bottom resting on the ground. The external battery enclosure is on the ground below the solar panel and secured to the poles.

B.4 WALL DH DATA LOGGER

The wall DH data logger was installed on the block wall facing, along with two multiplexer enclosures, a solar panel, and antenna. Two multiplexers were installed at Wall DH to accommodate the instruments from Lines 4 and 5. The data logger enclosure for this site was mounted midway between the two multiplexers. The data logger components at Wall DH include:

- Campbell Scientific CR1000 Datalogger
- Campbell Scientific BP12 12V 12 Amp-hour Battery
- Campbell Scientific AVW200 Vibrating Wire Interface
- Campbell Scientific CH 150 Charging Regulator
- Campbell Scientific AM 16/32B Multiplexer (in each multiplexer enclosure)
- 20 watt Solar Panel

Photographs of the data logger components and the data logger setup are shown in Photographs B-7 and B-8. The signal leads for instrument line 4 and 5 were routed through two 2-inch conduit runs over the precast coping to the respective multiplexers. Conduit was then run from each of the multiplexers to the data logger, with multiconductor cable connecting the components together. All data logger and multiplexer enclosures, solar panels, and antenna were installed on the masonry blocks.

COMPONENT

CAMPBELL SCIENTIFIC®
WHEN MEASUREMENTS MATTER

CR1000

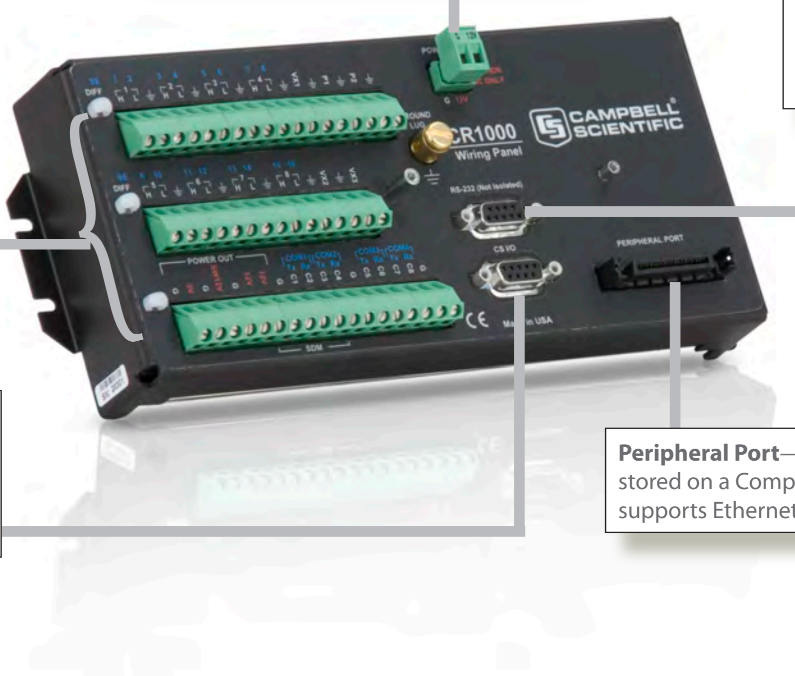
Measurement and Control Datalogger

Rugged, Reliable, and Ready for any Application

FIG. B-1
Sheet (1 of 8)

CR1000 Measurement and Control Datalogger

The CR1000 provides precision measurement capabilities in a rugged, battery-operated package. It consists of a measurement and control module and a wiring panel. Standard operating range is -25° to +50°C; an optional extended range of -55° to +85°C is available.



Input/Output Terminals—Individually configured for ratiometric resistive bridge, thermocouple, switch closure, high frequency pulse, low-level ac, serial sensors, and more.

Removable Power Terminal—simplifies connection to external power supply.

RS-232—provides a 9-pin DCE port for connecting a battery-powered laptop, serial sensors or RS-232 modems.

CS I/O Port—connects with AC-powered PCs and communication peripherals such as phone, RF, short-haul, and multidrop modems.

Peripheral Port—allows data to be stored on a CompactFlash card and/or supports Ethernet communications.

Benefits and Features

- 4 MB memory*
- Program execution rate of up to 100 Hz
- CS I/O and RS-232 serial ports
- 13-bit analog to digital conversions
- 16-bit H8S Renesas 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 ratio metric measurements
- Gas Discharge Tube (GDT) protected inputs
- Battery-backed SRAM memory and clock ensuring data, programs, and accurate time are maintained while the CR1000 is disconnected from its main power source
- Serial communications with serial sensors and devices supported via I/O port pairs
- PakBus®, Modbus, DNP3, TCP/IP, FTP, and SMTP protocols supported

Measurement and Control Module

The module measures sensors, drives direct communications and telecommunications, reduces data, controls external devices, and stores data and programs in on-board, non-volatile storage. The electronics are RF shielded and glitch protected by the sealed, stainless steel canister. A battery-backed clock assures accurate timekeeping. The module can simultaneously provide measurement and communication functions. The on-board, BASIC-like programming language supports data processing and analysis routines.

Wiring Panel

The CR1000WP is a black, anodized aluminum wiring panel that is compatible with all CR1000 modules. The wiring panel includes switchable 12 V, redistributed analog grounds (dispersed among analog channels rather than grouped), unpluggable terminal block for 12 V connections, gas-tube spark gaps, and 12 V supply on pin 8 to power our COM-series phone modems and other peripherals. The control module easily disconnects from the wiring panel allowing field replacement without rewiring the sensors. A description of the wiring panel's input/output channels follows.

FIG. B-1
Sheet (2 of 8)

**Originally, the standard CR1000 had 2 MB of data/program storage, and an optional version, the CR1000-4M, had 4 MB of memory. In September 2007, the standard CR1000 started having 4 MB of memory, making the CR1000-4M obsolete. Dataloggers that have a module with a serial number greater than or equal to 11832 will have a 4 MB memory. The 4 MB dataloggers will also have a sticker on the canister stating "4M Memory".*

Analog Inputs

Eight differential (16 single-ended) channels measure voltage levels. Resolution on the most sensitive range is 0.67 µV.

Pulse Counters

Two pulse channels can count pulses from high level (5 V square wave), switch closure, or low level AC signals.

Switched Voltage Excitations

Three outputs provide precision excitation voltages for resistive bridge measurements.

Digital I/O Ports

Eight ports are provided 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 CR1000 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 measurements), AC-powered PCs should use the CS I/O port instead of the RS-232 port (see above).

Peripheral Port

One 40-pin port interfaces with the NL116 Ethernet Interface and CompactFlash Module, the NL121 Ethernet Interface, or the CFM100 CompactFlash® Module.

Switched 12 Volt

This terminal provides unregulated 12 V that can be switched on and off under program control.

Storage Capacity

The CR1000 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. The storage capacity of the CR1000 can be increased by using a CompactFlash card.

Enclosure/Stack Bracket

A CR1000 housed in a weather-resistant enclosure can collect data under extremely harsh conditions. The 31551 and 31143 stack brackets allow a peripheral to be placed under the mounting bracket, thus conserving space. The 31143 is hinged, allowing easy access to the lower component during wiring or during maintenance.

Communication Protocols

The CR1000 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 CR1000 is used in conjunction with an NL240, NL201, NL116, or NL121. Refer to the CR1000 manual for more information.

Power Supplies

Typically, the CR1000 is powered with a PS200, PS150, or BPALK. The PS200 and PS150 provide a 7 Ah sealed rechargeable battery that should be connected to a charging source (either a power converter 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 BP7, BP12, and BP24 battery, which provide nominal ratings of 7, 12, and 24 Ah, respectively. The BP7 is typically used instead of the PS150 or PS200 when the battery needs to be mounted under the 31143 Hinged Stack Bracket. The BP12 and BP24 batteries are for powering systems that have higher current drain equipment such as satellite transmitters. The BP7, BP12, and BP24 should be connected to a regulated charging source (e.g., a CH200 or CH150 connected to a unregulated solar panel or power converter).

The PS200 (above) and CH200 can monitor charge input voltage, battery voltage, on-board temperature, battery current, and load current.

FIG. B-1
Sheet (3 of 8)

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.

Keyboard Display

The CR1000KD can be used to program the CR1000, manually initiate data transfer, and display data. The CR1000KD displays 8 lines by 21 characters (64 by 128 pixels) and has a 16-character keyboard. 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. One CR1000KD can be carried station to station in a CR1000 network.

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.

The CD100 has a vacuum flourescent display for responsive use through a very wide operating temperature range.

iOS Devices and Android Devices

An iOS device or Android device 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.

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 CR1000's RS-232 port via an RS-232 cable—no interface required.

External Data Storage Devices

A CFM100 or NL116 module can store the CR1000's data on an industrial-grade CompactFlash (CF) card. The CR1000 can also store data on an SC115 2 GB Flash Memory Drive.

Short Haul Modems

The SRM-5A RAD Short Haul Modem supports communications between the CR1000 and a PC via a four-wire unconditioned line (two twisted pairs).

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.

Internet and IP Networks

Campbell Scientific offers several interfaces that enable the CR1000 to communicate with a PC via TCP/IP.

Radios

Radio frequency (RF) communications are supported via narrowband UHF, narrowband VHF, spread spectrum, or meteor burst radios. Line-of-sight is required for all of our RF options.

Satellite Transmitters

Satellite transmitters offered by Campbell Scientific include an Argos transmitter, an Iridium transmitter, and an Inmarsat BGAN satellite IP terminal. Satellite telemetry offers an alternative for remote locations where phone lines or RF systems are impractical.

Telephone Networks

The CR1000 can communicate with a PC using landlines or cellular transceivers. A voice synthesized modem enables anyone to call the CR1000 via phone and receive a verbal report of real-time site conditions.

In Virginia, our RF500M Narrowband Radio Modem provides time- and event-driven ALERT data transmission.

FIG. B-1
Sheet (4 of 8)

Channel Expansion

4-Channel Low Level AC Module

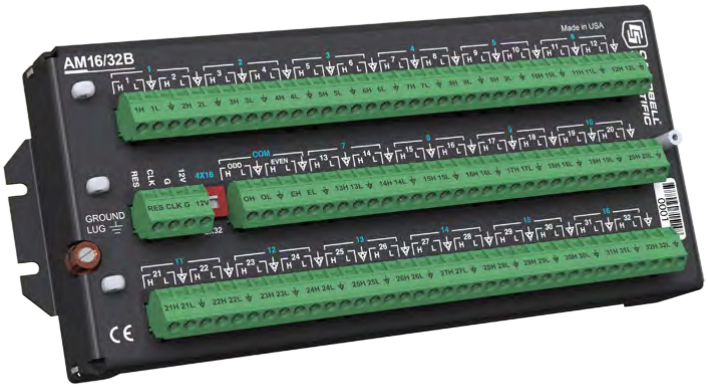
The LLAC4 is a small peripheral device that allows customers to increase the number of available low-level ac inputs by using control ports. This module is often used to measure up to four anemometers, and is especially useful for wind profiling applications.

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.

Multiplexers

Multiplexers increase the number of sensors that can be measured by a CR1000 by sequentially connecting each sensor to the datalogger. Several multiplexers can be controlled by a single CR1000.



The CR1000 is compatible with the AM16/32B (shown above) and AM25T multiplexers.

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 CR1000 via a direct communications link.

At www.campbellsci.com/downloads, the starter software can be downloaded at no charge. Our Resource DVD also provides this software as well as PDF versions of our brochures and manuals.

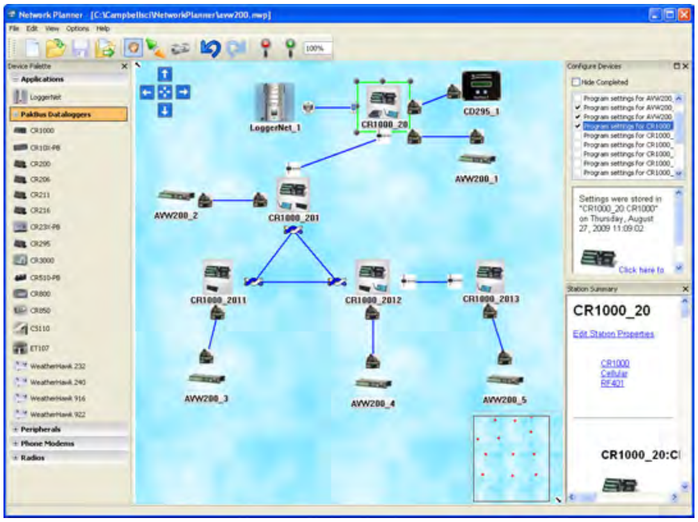
Datalogger Support Software

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.

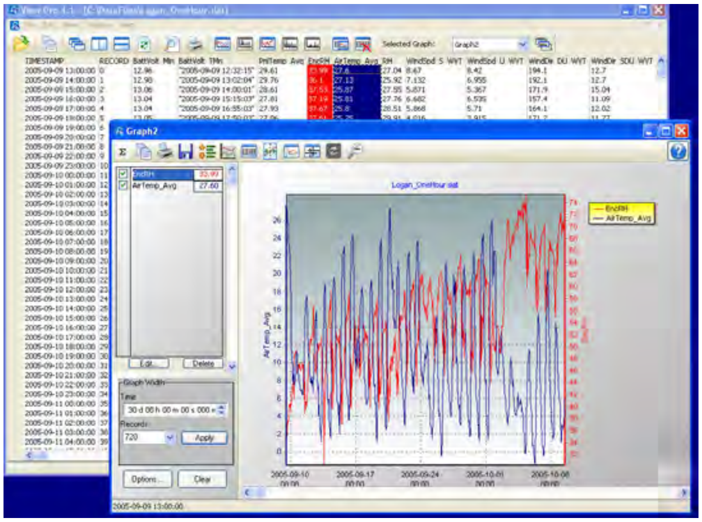
PC400, our mid-level software, supports a variety of telemetry options, manual data collection, and data display. For programming, it includes both Short Cut and the CRBasic program editor. PC400 does not support combined communication options (e.g., phone-to-RF), PakBus® routing, and scheduled data 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.



The Network Planner, included in LoggerNet 4 or higher, generates device settings and configures the LoggerNet network map for PakBus networks.



Both LoggerNet and RTDAQ use View Pro to display historical data in a tabular or graphical format.

FIG. B-1
Sheet (5 of 8)

Applications

The measurement precision, flexibility, long-term reliability, and economical price of the CR1000 make it ideal for scientific, commercial, and industrial applications.

Meteorology

The CR1000 is used in long-term climatological monitoring, meteorological research, and routine weather measurement applications.

Our rugged, reliable weather station measures meteorological conditions at St. Mary's Lake, Glacier National Park, MT.

Sensors the CR1000 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
- Cooled mirror hygrometers

Agriculture and Agricultural Research

The versatility of the CR1000 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

This vitaculture site in Australia integrates meteorological, soil, and crop measurements.

Wind Profiling

Our data acquisition systems can monitor conditions at wind assessment sites, at producing wind farms, and along transmission lines. The CR1000 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 CR1000 monitors electrical current, voltage, wattage, stress, and torque.

A Campbell Scientific system monitors an offshore wind farm in North Wales.

Photo courtesy npower renewables

Soil Moisture

The CR1000 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.

FIG. B-1
Sheet (6 of 8)

Air Quality

The CR1000 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).

Road Weather/RWIS

Our fully NTCIP-compliant Environmental Sensor Stations (ESS) are robust, reliable weather stations used for road weather/RWIS applications. A typical ESS includes a tower, CR1000, two road sensors, remote communication hardware, and sensors that measure wind speed and direction, air temperature, humidity, barometric pressure, solar radiation, and precipitation.

Water Resources/Aquaculture

Our CR1000 is well-suited to remote, unattended monitoring of hydrologic conditions. Most hydrologic sensors, including SDI-12 probes, interface directly to the CR1000.

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 CDM-VW300-series, 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 CR1000 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

A turbidity sensor was installed in a tributary of the Cedar River watershed to monitor water quality conditions for Seattle, Washington.

Vehicle Testing

This versatile, rugged datalogger is ideally suited for testing cold and hot temperature, high altitude, off-highway, and cross-country performance. The CR1000 is compatible with our SDM-CAN interface and GPS16X-HVS receiver.

Vehicle monitoring includes not only passenger cars, but airplanes, locomotives, helicopters, tractors, buses, heavy trucks, drilling rigs, race cars, and motorcycles.

The CR1000 can measure:

- **Suspension**—strut pressure, spring force, travel, mounting point stress, deflection, ride.
- **Fuel system**—line and tank pressure, flow, temperature, injection timing.
- **Comfort control**—ambient and supply air temperature, solar radiation, fan speed, ac on and off, refrigerant pressures, time-to-comfort, blower current.
- **Brakes**—line pressure, pedal pressure and travel, ABS, line and pad temperature.
- **Engine**—pressure, temperature, crank position, RPM, time-to-start, oil pump cavitation.
- **General vehicle**—chassis monitoring, road noise, vehicle position and speed, steering, air bag, hot/cold soaks, wind tunnels, traction, CANbus, wiper speed and current, vehicle electrical loads.

Other Applications

- Eddy covariance systems
- Wireless sensor/datalogger networks
- Fire weather
- Geotechnical
- Mesonet systems
- Avalanche forecasting, snow science, polar, high altitude
- Historic preservation

CR1000 Specifications

Electrical specifications are valid over a -25° to +50°C, non-condensing environment, unless otherwise specified. Recalibration recommended every three 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-SE16 or DIFF1-DIFF8)
8 differential (DF) or 16 single-ended (SE) individually configuredinput channels. Channel expansion provided by optional analog multiplexers.

RANGES and RESOLUTION: Basic resolution (Basic Res) is the A/D resolution of a single A/D conversion. A DIFF measurement with input reversal has better (finer) resolution by twice than 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 the 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*[4]	
			SE w/ No Rev	*DF w/ Input Rev*
250	250 µs	450 µs	~1 ms	~12 ms
60 Hz[5]	16.67 ms	3 ms	~20 ms	~40 ms
50 Hz[5]	20.00 ms	3 ms	~25 ms	~50 ms

[4] Includes 250 µs for conversion to engineering units.

[5] AC line noise filter.

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 Vdc

DC COMMON MODE REJECTION: >100 dB

NORMAL MODE REJECTION: 70 dB @ 60 Hz when using 60 Hz rejection

INPUT VOLTAGE RANGE W/O MEASUREMENT CORRUPTION: ±8.6 Vdc max.

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 GΩ 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-VX3)
3 switched voltage, sequentially active only during measurement.

RANGE AND RESOLUTION:

Channel	*Range*	*Resolution*	*Current Source/Sink*
(VX 1–3)	±2.5 Vdc	0.67 mV	±25 mA

ANALOG OUTPUT ACCURACY (VX):
±(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)

VX FREQUENCY SWEEP FUNCTION: Switched outputs provide a programmable swept frequency, 0 to 2500 mv square waves for exciting vibrating wire transducers.

PERIOD AVERAGE
Any of the 16 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)*		*Min Pulse Width (µV)*	*Max*[8] *Freq (kHz)*
		Min. (mV)[6]	*Max (V)*[7]		
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

[6] Signal centered around Threshold (see PeriodAvg() instruction).

[7] With signal centered at the datalogger ground.

[8] The maximum frequency = 1/(twice minimum pulse width) for 50% of duty cycle signals.

RATIOMETRIC MEASUREMENTS
MEASUREMENT TYPES: Provides ratiometric resistance measurements using voltage excitation. 3 switched voltage excitation outputs are available for measurement of 4- and 6-wire full bridges, and 2-, 3-, and 4-wire half bridges. Optional excitation polarity reversal minimizes dc errors.

RATIOMETRIC MEASUREMENT ACCURACY:[9,10, 11]
±(0.04% of Voltage Measurement + Offset)

[9] Accuracy specification assumes excitation reversal for excitation voltages < 1000 mV. Assumption does not include bridge resistor errors and sensor and measurement noise.

[10] Estimated accuracy, ΔX (where X is value returned from the measurement with Multiplier = 1, Offset = 0):
BrHalf() instruction: $\Delta X = \Delta V_1/V_X$
BrFull() instruction $\Delta X = 1000 \cdot \Delta V_1/V_X$, expressed as $mV \cdot V^{-1}$.
ΔV^{-1} is calculated from the ratiometric measurement accuracy. See Resistance Measurements Section in the manual for more information.

[11] Offsets are defined as:
Offset for DIFF w/input reversal = 1.5•Basic Res + 1.0 µV
Offset for DIFF w/o input reversal = 3•Basic Res + 2.0 µV
Offset for SE = 3•Basic Res + 3.0 µV
Excitation reversal reduces offsets by a factor of two.

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: 16.7×10^6

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 ac offsets up to ±0.5 Vdc.
Input Hysteresis: 12 mV RMS @ 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-C8)
8 ports software selectable, as binary inputs or control outputs. Provide on/off, pulse width modulation, edge timing, subroutine interrupts / wake up, switch closure pulse counting, high frequency pulse counting, asynchronous communications (UARTs), and SDI-12 communications. SDM communications are also supported.

LOW FREQUENCY MODE MAX: <1 kHz

HIGH-FREQUENCY MODE 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 Ω

INPUT STATE: high 3.8 to 16 V; low -8.0 to 1.2 V

INPUT HYSTERESIS: 1.4 V

INPUT RESISTANCE: 100 kΩ with inputs <6.2 Vdc
220 Ω with inputs ≥6.2 Vdc

SERIAL DEVICE/RS-232 SUPPORT: 0 TO 5 Vdc UART

SWITCHED 12 VDC (SW-12)
1 independent 12 Vdc unregulated source is switched on and off under program control. Thermal fuse hold current = 900 mA at 20°C, 650 mA at 50°C, 360 mA at 85°C.

CE COMPLIANCE
STANDARD(S) TO WHICH CONFORMITY IS DECLARED:
IEC61326:2002

COMMUNICATIONS
RS-232 PORTS:
DCE 9-pin: (not electrically isolated) for computer connection or connection of modems not manufactured by Campbell Scientific.
COM1 to COM4: 4 independent Tx/Rx pairs on control ports (non-isolated); 0 to 5 Vdc UART
Baud Rates: 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 telecommunications peripherals manufactured by Campbell Scientific.

SDI-12: Digital control ports C1, C3, C5, and C7 are individually configured and meet SDI-12 Standard v 1.3 for datalogger mode. Up to 10 SDI-12 sensors are supported per port.

PERIPHERAL PORT: 40-pin interface for attaching CompactFlash or Ethernet peripherals

PROTOCOLS SUPPORTED: PakBus, AES-128 Encrypted PakBus, Modbus, DNP3, FTP, HTTP, XML, HTML, POP3, SMTP, Telnet, NTCIP, NTP, Web API, SDI-12, SDM.

SYSTEM
PROCESSOR: Renesas H8S 2322 (16-bit CPU with 32-bit internal core running at 7.3 MHz)

MEMORY: 2 MB of flash for operating system; 4 MB of battery-backed SRAM for CPU usage and final data storage; 512 kB flash disk (CPU) for program files.

REAL-TIME CLOCK ACCURACY: ±3 min. per year. Correction via GPS optional.

REAL-TIME CLOCK RESOLUTION: 10 ms

SYSTEM POWER REQUIREMENTS
VOLTAGE: 9.6 to 16 Vdc

INTERNAL BATTERIES: 1200 mAh lithium battery for clock and SRAM backup that typically provides three years of backup

EXTERNAL BATTERIES: Optional 12 Vdc nominal alkaline and rechargeable available. Power connection is reverse polarity protected.

TYPICAL CURRENT DRAIN at 12 Vdc:
Sleep Mode: < 1 mA
1 Hz Sample Rate (1 fast SE meas.): 1 mA
100 Hz Sample Rate (1 fast SE meas.): 6 mA
100 Hz Sample Rate (1 fast SE meas. w/RS-232 communication): 20 mA
Active external keyboard display adds 7 mA (100 mA with backlight on).

PHYSICAL
DIMENSIONS: 23.9 x 10.2 x 6.1 cm (9.4 x 4 x 2.4 in); additional clearance required for cables and leads.

MASS/WEIGHT: 1 kg / 2.1 lb

WARRANTY
3 years against defects in materials and workmanship.

FIG. B-1
Sheet (8 of 8)

COMPONENT

CAMPBELL SCIENTIFIC®
WHEN MEASUREMENTS MATTER

CR800 Series

Measurement and Control Datalogger

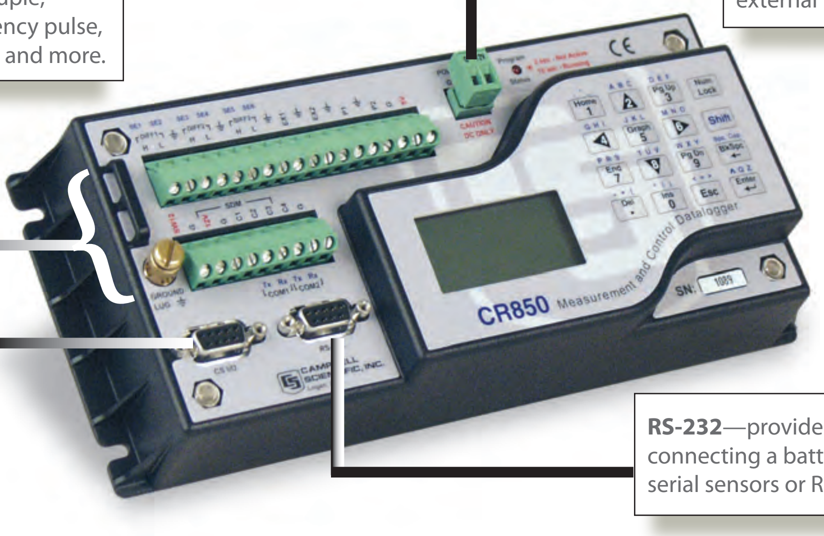
Rugged, Reliable, and Ready for any Application

FIG. B-2
Sheet (1 of 8)

More info: **435.227.9000**
campbellsci.com/cr800-series

CR800 and 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.



Input/Output Connections—Individually configured for ratiometric resistive bridge, thermocouple, switch closure, high frequency pulse, low-level ac, serial sensors, and more.

Removable Power Terminal—simplifies connection to external power supply.

CS I/O Port—connects with AC-powered PCs and communication peripherals such as phone, RF, short-haul, and multidrop modems.

RS-232—provides a 9-pin DCE port for connecting a battery-powered laptop, serial sensors or RS-232 modems.

Benefits and 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 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.

FIG. B-2
Sheet (2 of 8)

**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 Vdc that can be switched on and off under program control.

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.

The PS200 (above) and CH200 can monitor charge input voltage, battery voltage, on-board temperature, battery current, and load current.

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 NL201 or NL240.

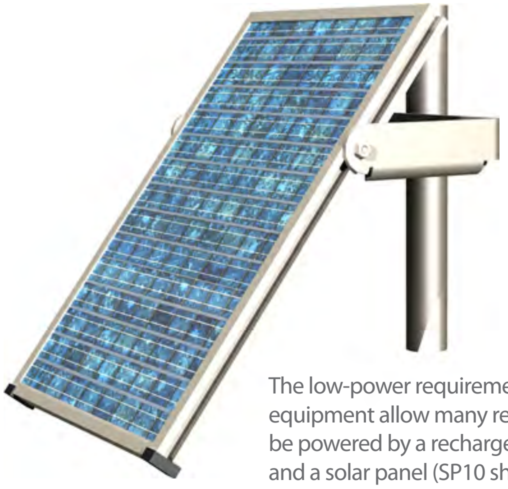
Enclosure/Stack Bracket

A CR800 or CR850 housed in a weather-resistant enclosure can collect data under extremely harsh conditions. The 31551 and 31143 stack brackets allow a peripheral to be placed under the mounting bracket, thus conserving space. The 31143 is hinged, allowing easy access to the lower component during wiring or during maintenance.

Power Supplies

Typically, the CR800 and CR850 dataloggers are powered using a PS200 power supply, PS150 power supply, or BPALK battery pack. The PS200 and PS150 provide a 7 Ah sealed rechargeable battery that should be connected to a charging source (either a power converter 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 BP7, BP12, and BP24 battery, which provide nominal ratings of 7, 12, and 24 Ah, respectively. The BP7 is typically used instead of the PS150 or PS200 when the battery needs to be mounted under the 31143 Hinged Stack Bracket. The BP12 and BP24 batteries are for powering systems that have higher current drain equipment such as satellite transmitters. The BP7, BP12, and BP24 should be connected to a regulated charging source (e.g., a CH200 or CH150 connected to a unregulated solar panel or power converter).



The low-power requirements of our equipment allow many remote sites to be powered by a rechargeable battery and a solar panel (SP10 shown above).

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 by 21 characters (64 by 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 and Android Devices

An iOS device or Android device 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 get our LoggerLink Mobile Apps.

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 or NL201 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.

Telephone Networks

The CR800 series can communicate with a PC using landlines or cellular 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

Satellite transmitters offered by Campbell Scientific include an Argos transmitter, an Iridium transmitter, and an Inmarsat BGAN satellite IP terminal. Satellite telemetry offers an alternative for remote locations where phone lines or RF systems are impractical.

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.

In Virginia, our RF500M Narrowband Radio Modem provides time- and event-driven ALERT data transmission.

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 DVD also provides this software as well as PDF versions of our brochures and manuals.

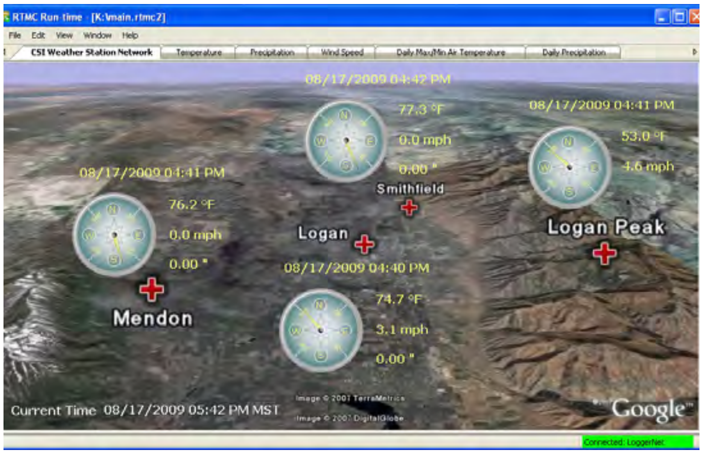
Datalogger Support Software

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.

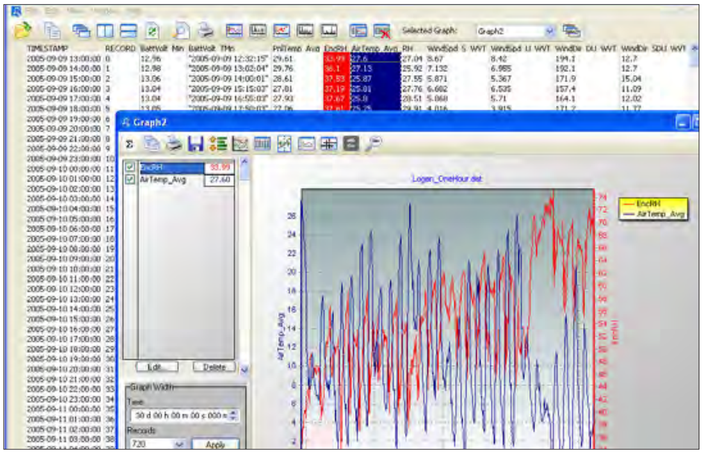
PC400, our mid-level software, supports a variety of telemetry options, manual data collection, and data display. For programming, it includes both Short Cut and the CRBasic program editor. PC400 does not support combined communication options (e.g., phone-to-RF), PakBus® routing, and scheduled data 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.



RTMC, a program for displaying the datalogger's data, is bundled with LoggerNet and RTDAQ. RTMCRT and RTMC Web Server clients also use forms created in the developer mode of RTMC.



Both LoggerNet and RTDAQ use View Pro to display historical data in a tabular or graphical format.

FIG. B-2
Sheet (5 of 8)

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.

Meteorological conditions affecting marine larvae distribution are monitored at Exuma Cay, Bahamas.

Sensors the CR800 series can measure include:

- 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

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.

FIG. B-2
Sheet (6 of 8)

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 CDM-VW300-series, 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 three 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 (DIFF) or 6 single-ended (SE) individually configured input channels. Channel expansion provided by optional analog multiplexers.

RANGES and RESOLUTION: Basic resolution (Basic Res) is the resolution of a single A/D conversion. A DIFF measurement with input reversal has better (finer) resolution by by twice than Basic Res.

Range (mV)[1]	*DIFF 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 DIFF 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 DIFF w/input reversal = 1.5·Basic Res + 1.0 µV
Offset for DIFF 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*[4]	
			SE w/ No Rev	*DIFF w/ Input Rev*
250	250 µs	450 µs	~1 ms	~12 ms
60 Hz[5]	16.67 ms	3 ms	~20 ms	~40 ms
50 Hz[5]	20.00 ms	3 ms	~25 ms	~50 ms

[4] Includes 250 µs for conversion to engineering units.

[5] AC line noise filter.

INPUT NOISE VOLTAGE: For DIFF 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

INPUT VOLTAGE RANGE W/O MEASUREMENT CORRUPTION: ±8.6 Vdc max.

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 GΩ 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 outputs sequentially active only during measurement.

RANGE AND RESOLUTION:

Channel	*Range*	*Resolution*	*Current Source/Sink*
(VX 1–2)	±2.5 Vdc	0.67 mV	±25 mA

Voltage outputs programmable between ±2.5 V with 0.67 mV resolution.

ANALOG OUTPUT ACCURACY (VX):
±(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)

Vx FREQUENCY SWEEP FUNCTION: Switched outputs provide a programmable swept frequency, 0 to 2500 mv square waves for exciting vibrating wire transducers.

PERIOD AVERAGE
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)*	*Input Signal (peak to peak)*		*Min Pulse Width (µV)*	*Max*[8] *Freq (kHz)*
		Min (mV)[6]	*Max (V)*[7]		
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

[6] Signal centered around *Threshold* (see **PeriodAvg()** instruction).

[7] Signal centered around datalogger ground.

[8] Maximum frequency = 1/(twice minimum pulse width) for 50% of duty cycle signals.

RATIOMETRIC MEASUREMENTS
MEASUREMENT TYPES: Provides ratiometric resistance measurements using voltage excitation. Three switched voltage excitation outputs are available for measurements of 4- and 6-wire full bridges, and 2-, 3-, and 4-wire half bridges. Optional excitation polarity reversal minimizes dc errors.

RATIOMETRIC MEASUREMENT ACCURACY:[9,10, 11]
±(0.04% of voltage measurement + offset)

[9] Accuracy specification assumes excitation reversal for excitation voltages < 1000 mV. Assumption does not include bridge resistor errors and sensor and measurement noise.

[10] Estimated accuracy, ΔX (where X is value returned from the measurement with Multiplier =1, Offset = 0):
BrHalf() instruction: $\Delta X = \Delta V_1/V_X$
BrFull() instruction $\Delta X = 1000 \cdot \Delta V_1/V_X$, expressed as $mV \cdot V^{-1}$.
ΔV^{-1} is calculated from the ratiometric measurement accuracy. See Resistance Measurements Section in the manual for more information.

[11] Offsets are defined as:
Offset for DIFF w/input reversal = 1.5•Basic Res + 1.0 µV
Offset for DIFF w/o input reversal = 3•Basic Res + 2.0 µV
Offset for SE = 3•Basic Res + 3.0 µV
Excitation reversal reduces offsets by a factor of two.

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: 16.7×10^6

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 on/off, pulse width modulation, edge timing, subroutine interrupts/wake up, switch closure pulse counting, high-frequency pulse counting, asynchronous communications (UARTs), SDI-12 communications, and SDM communications.

LOW FREQUENCY MODE MAX: <1 kHz

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 Ω

INPUT STATE: high 3.8 to 16 V; low -8.0 to 1.2 V

INPUT HYSTERISIS: 1.4 V

INPUT RESISTANCE:
100 kΩ with inputs <6.2 Vdc
220 Ω with inputs ≥6.2 Vdc

SERIAL DEVICE / RS-232 SUPPORT: 0 to 5 Vdc UART

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:
DCE 9-pin: (not electrically isolated) for computer connection or connection of modems not manufactured by Campbell Scientific.
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 telecommunication peripherals manufactured by Campbell Scientific

SDI-12: Digital control ports C1 or C3 are individually configurable and meet SDI-12 Standard version 1.3 for datalogger mode. Up to 10 SDI-12 sensors are supported per port.

PROTOCOLS SUPPORTED: PakBus, AES-128 Encrypted PakBus, Modbus, DNP3, FTP, HTTP, XML, HTML, POP3, SMTP, Telnet, NTCIP, NTP, Web API, 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

INTERNAL BATTERIES: 1200 mA h lithium battery for clock and SRAM backup, typically provides 3 years of backup

EXTERNAL BATTERIES: Optional 12 Vdc nominal alkaline and rechargeable available. Power connection is reverse polarity protected.

TYPICAL CURRENT DRAIN @ 12 Vdc:
Sleep Mode: 0.7 mA typical; 0.9 mA max.
1 Hz Sample Rate (1 fast SE measurement): 1 mA
100 Hz Sample Rate (1 fast SE measurement): 16.2 mA
100 Hz Sample Rate (1 fast SE meas w/RS-232 communication): 28 mA
Active external keyboard display adds 7 mA (100 mA with backlight on).

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: 0.7 kg (1.5 lb)

WARRANTY
3-years against defects in materials and workmanship.

FIG. B-2
Sheet (8 of 8)

Model 8002 Series *(LC-2, LC-2A, LC-2×4, LC-2×16)*

LC-2 Series Dataloggers

Applications

The LC-2 series dataloggers are used to read all Geokon vibrating wire instruments. Sensors that can be read and monitored include…

- **Piezometers**
- **Precision water level sensors**
- **Crackmeters**
- **Settlement systems**
- **Temperature sensors**

● *Model 8002-1A-1 (LC-2A).*

● *Model 8002-4-1 (LC-2×4).*

● *Model 8002-16-1 (LC-2×16).*

● *Model 8002-16-1 (LC-2×16) 16-Channel, Model 8002-4-1 (LC-2×4) 4-Channel and Model 8002-1-1 (LC-2) Single-Channel Dataloggers.*

Operating Principle

The Model 8002 LC-2 Series Dataloggers are designed to read both the vibrating wire element and the integral thermistor of any Geokon vibrating wire sensor.

The LC-2 (internal hard wired transducer connection) and LC-2A (10-pin transducer connector option) are designed to be standalone, single-channel dataloggers, which makes them especially useful for the remote and continuous monitoring of isolated sensors.

The LC-2×4 is a self-contained, 4-channel version (vibrating wire with thermistor) of the LC-2, and the LC-2×16 is a 16-channel (vibrating wire with thermistor) version.

All LC-2 Series Dataloggers are housed inside Fiberglass NEMA 4X enclosures, which makes them very robust, weather-proof and particularly well-suited to operation in harsh environments. Low power consumption provides long battery life. The condition of the main batteries is reported as an element in the data array.

Data memory consists of 320K bytes of EEPROM. This translates into a memory storage capacity of 16,000 arrays for the LC-2 and LC-2A, 10,666 arrays for the LC-2×4 and 3,555 arrays for the LC-2×16. Each array consists of the datalogger ID, day (Julian or month/day format), time (HHMM), seconds, main battery voltage, datalogger temperature, vibrating wire sensor reading (in engineering units), the sensor temperature and array number. The array transmission is in comma delineated ASCII text, for easy importation into popular spreadsheet programs.

Up to 6 intervals may be specified from a logarithmic table, with a maximum of 255 iterations. The programmed intervals can be started or stopped once at preset times of the day.

Power

The Model 8002 LC-2 Series Dataloggers are powered by easily accessible, alkaline D cells, or by an external 12 V source. For extended battery life, a solar panel and rechargeable batteries can be used.

Communications

The Model 8002 LC-2 Series Dataloggers are available with an RS-232 Serial Interface or with a direct USB 2.0 connection; patch cords are supplied for this purpose.

FIG. B-3
Sheet (1 of 2)

Technical Specifications

	Single-Channel	4-Channel	16-Channel
	LC-2, LC-2A	**LC-2×4**	**LC-2×16**
Measurement Accuracy	±0.05% F.S. (450-4000 Hz)	±0.05% F.S. (450-4000 Hz)	±0.05% F.S. (450-4000 Hz)
Measurement Resolution	1 part in 20,000	1 part in 20,000	1 part in 20,000
Program Memory	24K FLASH	24K FLASH	24K FLASH
Data Memory	320K EEPROM	320K EEPROM	320K EEPROM
Data Connection	RS-232, USB or RS-485	RS-232, USB or RS-485	RS-232, USB or RS-485
Storage Capacity (Arrays)	16,000[1]	10,666	3,555
Temperature Range	−30˚C to +50˚C	−30˚C to +50˚C	−30˚C to +50˚C
Temperature Measurement	*(accuracy)* 2.0% F.S. *(resolution)* 0.1°C	*(accuracy)* 2.0% F.S. *(resolution)* 0.1°C	*(accuracy)* 2.0% F.S. *(resolution)* 0.1°C
Communication Speed	9600 bps	9600 bps	9600 bps
Communication Parameters	8 data bits, no parity, 1 stop bit	8 data bits, no parity, 1 stop bit	8 data bits, no parity, 1 stop bit
Power Supply	3 VDC (2 Alkaline 'D' cells)	3 VDC (2 Alkaline 'D' cells)	3 VDC (4 Alkaline 'D' cells)
Communication Current	< 100 mA	< 100 mA	< 100 mA
Measurement Current	< 200 mA	< 200 mA	< 200 mA
Quiescent Current	< 500 μA	< 500 μA	< 500 μA
Scan Interval	3 - 86,400 seconds (24 hours)	10 - 86,400 seconds (24 hours)	30 - 86,400 seconds (24 hours)
Operating Time (20˚C)	3 days - 3 years, depending on scan interval	8 days - 2 years, depending on scan interval	8 days - 2 years, depending on scan interval
Sensor Connection	*(LC-2)* Hard wired *(LC-2A)* 10-pin Connector	Hard wired	Hard wired
L × W × H	122 × 120 × 91 mm	260 × 160 × 91 mm	318 × 277 × 159 mm[2]

[1] *8,000 arrays when used with LogWare software.*

[2] *Does not include mounting feet.*

Ordering Information

	Single-Channel	4-Channel	16-Channel
Data Connection	**LC-2, LC-2A**	**LC-2×4**	**LC-2×16**
RS-232	Model 8002-1-1, Model 8002-1A-1	Model 8002-4-1	Model 8002-16-1
USB	Model 8002-1-2, Model 8002-1A-2	Model 8002-4-2	Model 8002-16-2
RS-485	Model 8002-1-3, Model 8002-1A-3	Model 8002-4-3	Model 8002-16-3

Software

LogView Software simplifies the task of configuration, communication, monitoring, data collection and data reduction using the Model 8002 (LC-2) Series Dataloggers.

LogView is compatible with Windows® 2000, XP, XP Pro, Vista and 7.

Please see the Model 8001-3 LogView Software data sheet for more information.

FIG. B-3
Sheet (2 of 2)

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*

| Doc. Rev. E.1, 02/15

Description

The SAA232 is a digital interface unit used in earth stations. It allows the Data Logger to communicate with the SAA by converting the RS232 communication protocol used by the Data Logger to the RS485 communication protocol used in the SAA. In addition to allowing communications between the Data Logger and the SAA, the SAA232 limits the SAA power consumption by only applying power to the SAA when the RS232 port is active. It also incorporates a resettable fuse and surge protection.

There are two different SAA232 interface types: the SAA232, and the SAA232-5. The SAA232 is used to connect a single SAA to a single COM port on the Data Logger, while the SAA232-5 can be used to connect up to 5 SAAs to a single COM port. Both types incorporate galvanic isolation between the SAA and Data Logger. SAA power supply is conditioned by a DC/DC converter that boosts the battery voltage to 13.5V (or 16.5V set through software) which is often necessary for long SAAs or long cable runs.

The SAA232 must be grounded to minimize the risk of damage by voltage transients associated with power surges and lightning induced transients. Earth grounding is required to form a complete circuit for voltage clamping devices internal to the SAA232.

Related products: SAA, SAAReg, SAASPD, SAAPZ

Specifications

Dimensions:	30 mm x 121 mm x 51 mm
Mounting:	2 x 5 mm holes, spaced 102 mm
Weight:	0.31 kg
Operating temperature:	-40°C to +80°C
Operating humidity:	0% to 95% Non-condensing
LED indicators:	1 – Power On
Power requirements:	9.5 V to 16 V

FIG. B-4
Sheet (1 of 2)

Output power:	13.5 V automated software adjusted 16.5 V
Standby current consumption:	0.2 mA
Operating current consumption:	30 mA active
Power up time:	10 ms
Data receive delay to power off:	4 s (or program shut down)
Serial protocol:	RS232 to RS485, slew rate limited
Data rate:	38.4 kbps to 230.4 kbps
Surge suppression:	600 W (10/1000 µs), 4 kW (8/20 µs), 2kA (8/20 µs) from gas discharge

Wiring Diagram

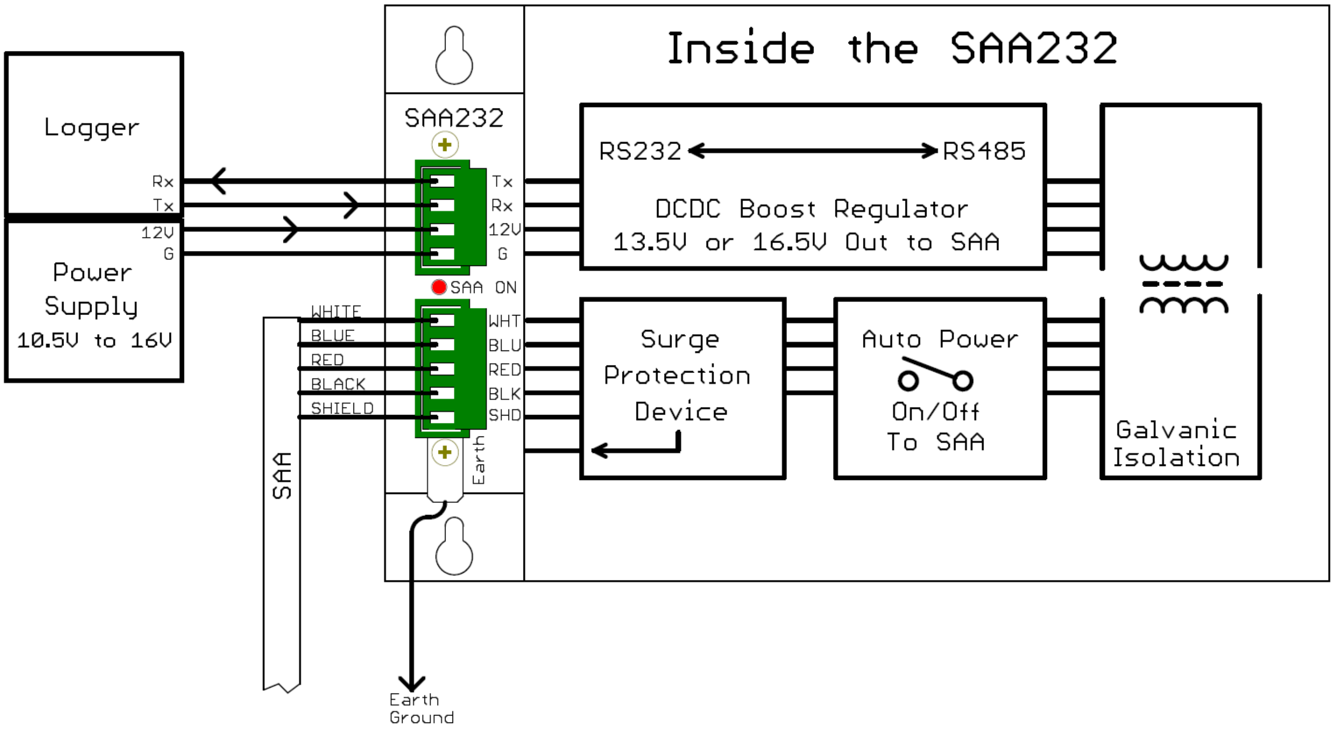


FIG. B-4
Sheet (2 of 2)

Optical Sensing Interrogator | sm225

Applications

- Full Spectrum Measurements of fiber Bragg grating (FBG), extrinsic Fabry-Perot , long period grating (LPG), and other optical sensor components.
- Continuous long-term health monitoring of bridges, dams, buildings, tunnels, ships, aircraft, trains, and other complex structures.
- Development of fiber optic sensors and transducers.

Features

- High accuracy absolute measurements of strain, temperature, displacement, pressure and other static sensors.
- On-board NIST traceable wavelength reference.
- Wide wavelength swept laser supporting dozens of sensors per channel.
- Up to 16 integrated measurement channels.
- Direct mounting to any standard 19” EIA/IEC equipment rack.

Deployments

- Civil structures (bridges, dams, tunnels, mines, buildings).
- Oil & gas (well reservoir management, platform structural health, pipeline condition).
- Marine vessels (hull, mast, rudder, deck, cargo containers).
- Transportation (railways, trains, roadways, specialty vehicles, cranes).
- Homeland security (perimeter intrusion, heat detection, security gate monitoring).
- Medical devices (probes, catheters).

Description

The sm225 Optical Sensing Interrogator is an industrial grade, rack mounted static optical sensor interrogation module that facilitates up to 16 internal fiber measurement channels.

The sm225 Optical Sensing Interrogator is built upon the Micron Optics x25 optical interrogator core, featuring a high power, low noise swept wavelength laser, realized with Micron Optics patented Fiber Fabry-Perot Tunable Filter technology. The x25 interrogator core employs full spectral scanning and data acquisition, providing measurements with high absolute accuracy, flexible software post-processing, and high dynamic range performance. x25 based interrogators support continuous on-board NIST traceable wavelength reference components and are ideally suited to measure many different optical sensor types, including FBGs, long period gratings, extrinsic Fabry-Perot sensors, and many others. Well over half of the fiber optic sensors deployed today are measured with instrumentation that uses Micron Optics technology.

The Micron Optics “sm - Sensing Module” platform responds directly to the user commands of the optical interrogator core and outputs sensor wavelength data via Ethernet port and custom protocol. All module settings, sensor calculations, data visualization, storage, and alarming tasks are run on an external PC or optional internal sensor processor module. The Sensing Module platform is ideal for custom, client developed system management tools, but is equally compatible with local or remote installations of Micron Optics ENLIGHT.

sm225 Rack Mount Module

Micron Optics ENLIGHT Sensing Analysis Software is included with Micron Optics sensing interrogator systems and provides a single suite of tools for data acquisition, computation, and analysis of optical sensor networks. ENLIGHT combines the useful features of traditional sensor software with the specific tools needed to optimize optical properties during the design, implementation, and operations phases of an optical sensor system. Tables, graphs, and additional data visualization features make ENLIGHT easy to use. Learn more about ENLIGHT at http://www.micronoptics.com/sensing_software.php.

FIG. B-5
Sheet (1 of 2)

Optical Sensing Interrogator | sm225

Specifications β[1]

Optical Properties

	sm225-200	sm225-500	sm225-800
Number of Optical Channels	1	4	16
Scan Frequency	1 Hz	2 Hz	0.5 Hz
Wavelength Range	1520-1580 nm	1510-1590 nm	1510-1590 nm
Wavelength Accuracy [2]	10 pm	1 pm	1 pm
Wavelength Stability [3]	5 pm	1 pm	1 pm
Wavelength Repeatability [4]	1pm at 1Hz	0.5pm at 1Hz, 0.2 pm at 0.1Hz	1pm at 0.5Hz
Dynamic Range[5]	40dB	50 dB	40dB
Typical FBG Sensor Capacity[6]	15	80	320
Full Spectrum Measurement	Included		
Internal Peak Detection Mode	Included		
sm041 Switch Compatible	No	No	Switches internal
Optical Connectors	FC/APC (E2000 available)		

Data Processing Capabilities

Interfaces	Ethernet - other interfaces available via an optional Internal Sensing Processor
Protocols	Custom Micron Optics protocol via Ethernet
Remote Software	Spectral analysis, peak detection, data logger, peak tracking, and instrument control
LabVIEW™ Source Code	Allows for customization of remote software
Enhanced Data Management	ENLIGHT Sensing Analysis Software

Mechanical, Environmental, Electrical Properties

Dimensions; Weight	435 mm x 442 mm x 45 mm; 4.1 kg (9 lbs max)
Rack Mount Hardware	Included
Operating Temperature; Humidity	0° to 50°C; 0 to 80%, non-condensing
Storage Temperature; Humidity	-20° to 70°C; 0 to 95%, non-condensing
Input Voltage	7 - 36 VDC (100~240 VAC, 47~63Hz), AC/DC converter included
Power Consumption at 12V	20 W typ, 30 max

Options

Scan Frequency [7]	2, 5, or 10 Hz
Internal Sensing Processor w/ 3 Relays	Windows XP Professional or Linux OS, See sp125 datasheet for processor specs

Notes:

1. Beta product. For details see www.micronoptics.com/product_designation.php.
2. Per NIST Technical Note 1297, 1994 Edition, Section D.1.1.1, definition of "accuracy of measurement".
3. Captures effects of long term use over full operating temperature range of the instrument.
4. Per NIST Technical Note 1297, 1994 Edition, Section D.1.1.2, definition of "repeatability [of results of measurements]".
5. Defined as laser launch power minus detection noise floor.
6. Assuming nominal wavelength range of +/- 2nm per FBG sensor.
7. 10 Hz scan rate available with 40 nm (1525-1565nm) wavelength range.

FIG. B-5
Sheet (2 of 2)

MORNINGSTAR
World's Leading Solar Controllers & Inverters

Product shown with optional meter.

Morningstar's ProStar is the world's leading mid-range solar controller for both professional and consumer applications. This second generation ProStar:

- Adds new features and protections using highly advanced technology
- Provides longer battery life and improved system performance
- Sets new standards for reliability and self-diagnostics

Standard Features:

- Versions available: 15 or 30 amp
  12 / 24 or 48 volt
  negative or positive ground
- Estimated 15 year life
- PWM series battery charging (not shunt)
- 3-position battery select: gel, sealed or flooded
- Very accurate control and measurement
- Jumper to eliminate telecom noise
- Parallel for up to 300 amps
- Temperature compensation
- Tropicalization: conformal coating, stainless steel fasteners & anodized aluminum heat sink
- No switching or measurement in the grounded leg
- 100% solid state
- Very low voltage drops
- Current compensated low voltage disconnect (LVD)
- LED's indicate battery status and faults
- Capable of 25% overloads
- Remote battery voltage sense terminals

Electronic Protections:

- Short-circuit — solar and load
- Overload — solar and load
- Reverse polarity
- Reverse current at night
- High voltage disconnect
- High temperature disconnect
- Lightning and transient surge protection
- Loads protected from voltage spikes
- Automatic recovery with all protections

FIG. B-6
Sheet (1 of 2)

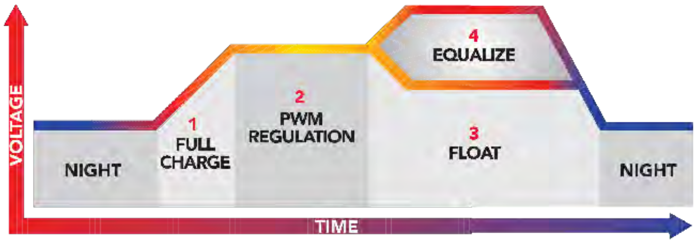
ProStar™ TECHNICAL SPECIFICATIONS

ProStar Options

- Digital meter
  - Highly accurate voltage and current display
  - Low self-consumption (1 mA)
  - Includes manual disconnect button
  - Displays 5 different protection functions and disconnect conditions
  - Self-diagnostics (self-test) provides a comprehensive test of the ProStar —
    - Displays 9 different controller status parameters, including temperature
    - Displays detected faults
- Positive ground
- Remote temperature probe

Optimized Battery Charging

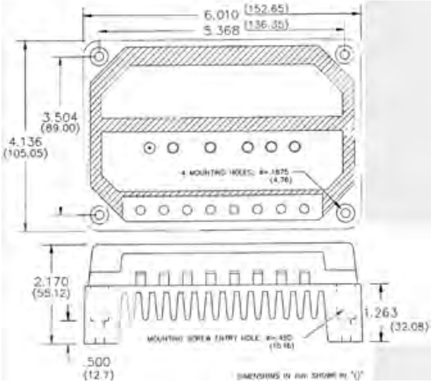
The ProStar has four stages of charging to provide increased battery capacity and life.



Mechanical Specifications

Weight:
12 oz
(0.34 kg)

Wire Size:
#6 AWG
(16 mm2)



ProStar Versions

	PS-15	PS-30	PS15M-48V
Rated Solar Current	15A	30A	15A
Rated Load Current	15A	30A	15A
System Voltage	15A	30A	15A
Options			
Digital Meter	yes	yes	standard
Positive Ground	no	yes	yes
Remote Temp. Probe	yes	yes	yes

Battery Voltage Setpoints*

	Gel	Sealed	Flooded
Regulation Voltage	14.0	14.15	14.4
Float	13.7	13.7	13.7
Equalization	n/a	14.35	14.9/15.1
Load Disconnect	11.4	11.4	11.4
Load Reconnect	12.6	12.6	12.6

Note: values are for 12V. Use 2X for 24V and 4X for 48V.

Electrical Specifications

	12V	24V	48V
Temp. Comp. (mV/˚C)*	– 30mV	– 60mV	– 120mV
Accuracy	40mV	60mV	80mV
Min. Voltage to Operate	8V	8V	15V
Self-consumption	22mA	25mA	28mA
Lvd Current Coefficient**	– 20mV	– 40mV	– 80mV
Charge Algorithm		PWM, constant voltage	
Operating Temperature		– 40˚C to + 60˚C	
Digital Display:			
Operating Temp.		– 30˚C to + 85˚C	
Voltage Accuracy		0.5%	
Current Accuracy		2.0%	
Self-Consumption		1 mA	

* 25˚C Reference

** Per Amp of Load

FIG. B-6
Sheet (2 of 2)

WARRANTY: Five year warranty period. Contact Morningstar or your authorized distributor for complete terms.

CE RoHS COMPLIANT REACH COMPLIANT

MORNINGSTAR
World's Leading Solar Controllers & Inverters
www.morningstarcorp.com

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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 Barometer & Pressure Transducers

- *Model 4580-1 Barometer (inset), Model 4580-2 and 4589-2V Pressure Transducers.*

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. The Model 4580-1 is a barometer used 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.

FIG. B-7
Sheet (3 of 4)

Technical Specifications

Model	Standard Ranges	Over Range	Resolution	Accuracy[1]	Linearity	Temperature Range[2]	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 cm^3 at F.S.	133 × 19.1 mm	0.12 kg
4500SH	−100 kPa 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 cm^3 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 cm^3 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 cm^3 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 cm^3 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 cm^3 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 cm^3 at F.S.	203 × 38.1 mm	1.50 kg
4500H[3]	−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 cm^3 at F.S.	140 × 32 mm[4] 140 × 25.4 mm	0.30 kg
4500HH[3]	−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 cm^3 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 cm^3 at F.S.	133 × 19.1 mm	0.12 kg
4500Ti	−100 to 350, 700 kPa; 1, 2, 3, 5, 7.5 MPa[2]	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 cm^3 at F.S.	125 × 25.4 mm	0.19 kg
4580-1 (Barometer)	200 Mbar[2]	2 × rated pressure	0.025% F.S.[5]	±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.[5]	±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.[5]	±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 × 63.5 mm	1.72 kg
4500AR[6]	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.[5]	±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 cm^3 at F.S.	varies according to pressure range	varies according to pressure range

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

[1] Accuracy established under laboratory conditions.

[2] Other ranges available on request.

[3] 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.

[4] For 70 and 170 kPa range only.

[5] Depends on readout system.

[6] 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.

FIG. B-7
Sheet (4 of 4)

Photograph B-1. Abutment 4 vibrating wire data logger internal components.

Photograph B-2. Abutment 4 vibrating wire data logger and solar panel.

CDOT GRS Instrumentation
I-70 Over Smith Road
Aurora, Colorado

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FIG. B-8
Sheet 1 of 5

Photograph B-3. Multiplexer 1 at abutment 4.

Photograph B-4. Multiplexers 1 through 4 installed on sheet pile at abutment 4.

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FIG. B-8
Sheet 2 of 5

Photograph B-5. Abutment 4 fiber optic data logger components.

Photograph B-6. Abutment 4 fiber optic data logger.

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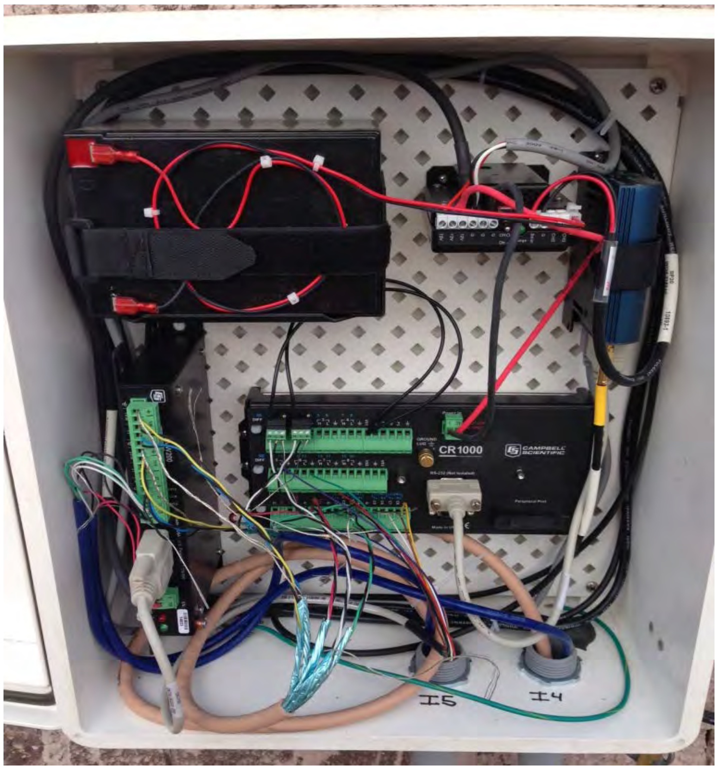
FIG. B-8
Sheet 3 of 5



Photograph B-7. Wall DH data logger components.

Photograph B-8. Wall DH data logger, multiplexers, and solar panel.

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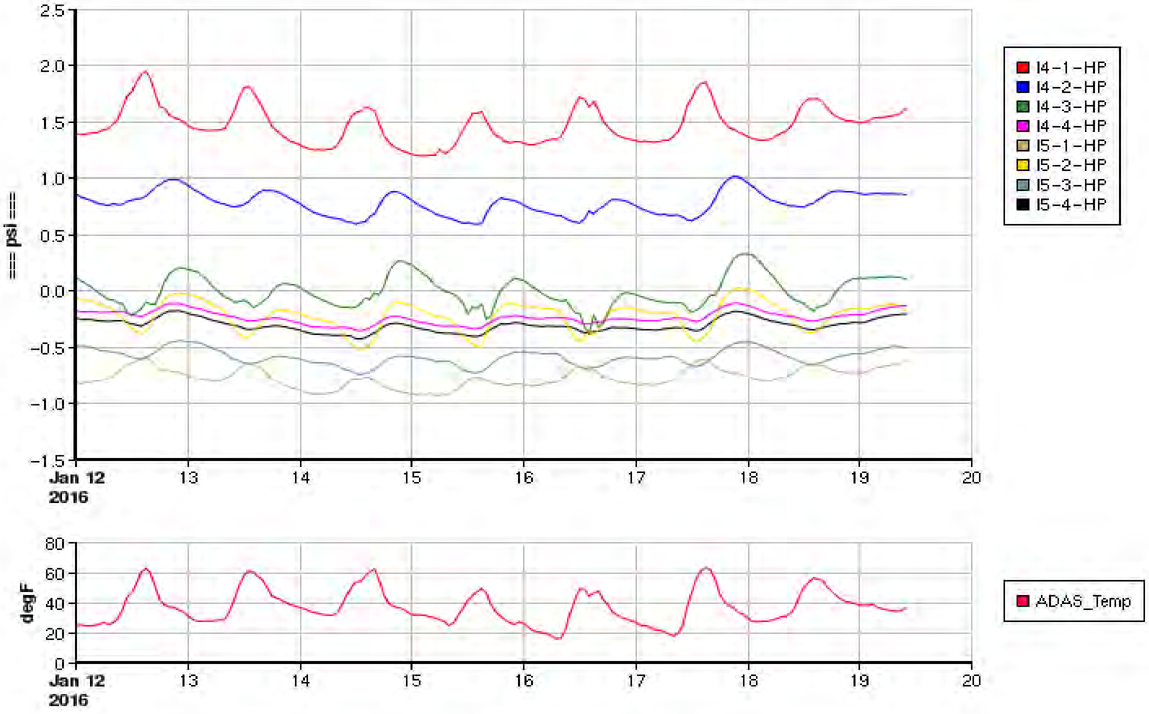
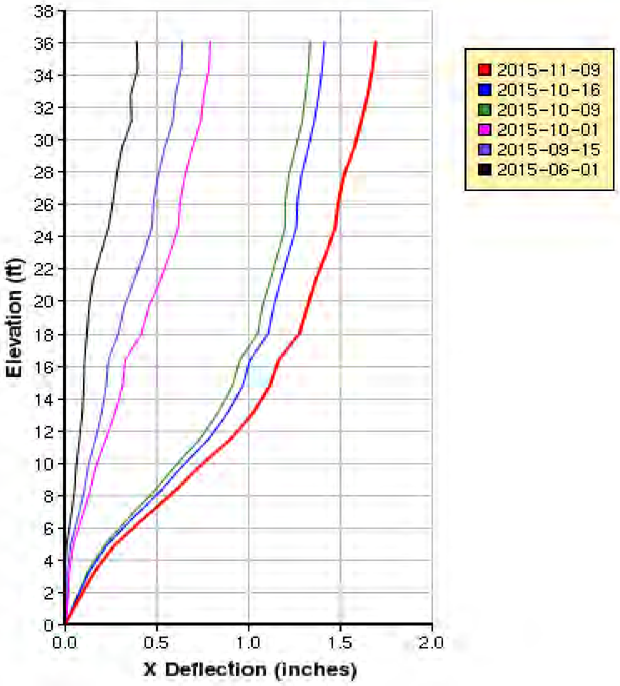
FIG. B-8
Sheet 4 of 5



Photograph B-9. Sample graph of horizontal pressure gages, Lines 4 and 5.



Photograph B-10. Sample summary graph of ShapeAccelArray.

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FIG. B-8
Sheet 5 of 5

APPENDIX C – CONSTRUCTION SCHEDULE

CONSTRUCTION SCHEDULE

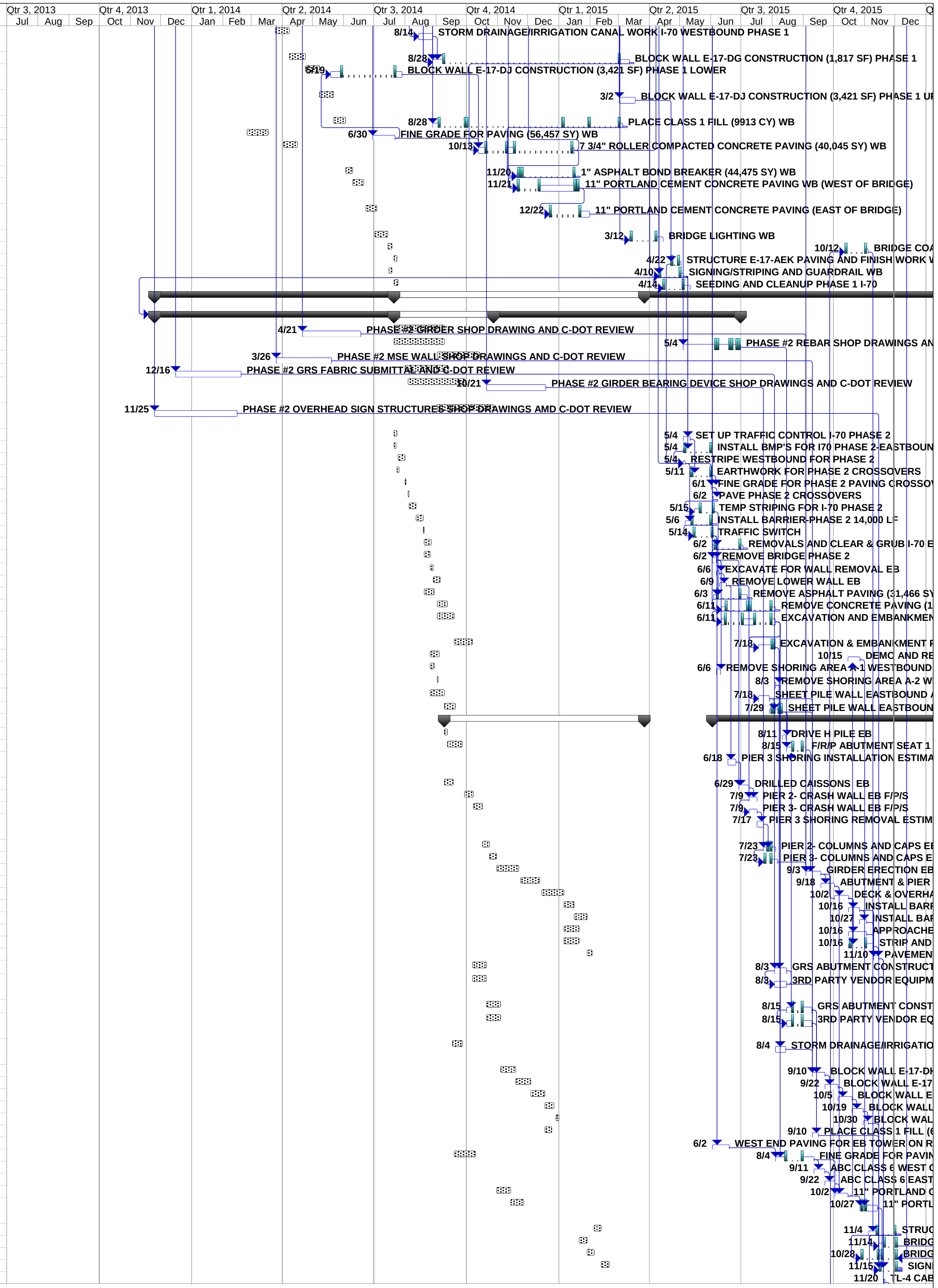
CDOT I70 Tower to Colfax 11.30.15 Status 1

ID	ID	Task Name	Duration	Start	Finish	Constraint Date	Remaining Duration	Critical	Predecessors	Successors	Actual Start
1	1	**CDOT-I-70 TOWER TO COLFAX**	0 days	Thu 8/15/13	Thu 8/15/13	NA	0 days	No		3	Thu 8/15/13
2	**2**	**ADMINISTRATIVE**	**335.5 days**	**Thu 8/15/13**	**Mon 4/6/15**	**NA**	**0 days**	**Yes**			**Thu 8/15/13**
3	3	BID DATE	1 day	Thu 8/15/13	Thu 8/15/13	NA	0 days	No	1	4	Thu 8/15/13
4	4	CDOT & UPRR Agreement	69 days	Thu 8/15/13	Thu 11/21/13	NA	0 days	No	3	5,10,37,14	Thu 8/15/13
5	5	AWARD AND CONTRACTS	38 days	Thu 8/15/13	Mon 9/30/13	NA	0 days	No	4	6	Thu 8/15/13
6	6	NOTICE TO PROCEED (RECEIVED 9/30)	1 day	Mon 9/30/13	Mon 9/30/13	NA	0 days	No	5	37,35,7,8,26,27,28,29,30,	Mon 9/30/13
7	7	CITY OF AURORA PERMIT	14 days	Tue 10/1/13	Fri 10/18/13	NA	0 days	No	6	18	Tue 10/1/13
8	8	PUBLIC INFORMATION SERVICE	16 days	Tue 10/1/13	Tue 10/22/13	NA	0 days	No	6	18	Tue 10/1/13
9	9	UPRR C&M AGREEMENT	17 days	Wed 10/30/13	Fri 11/22/13	NA	0 days	No	6	18	Wed 10/30/13
10	10	UPRR PERMITS SUBMITTALS ROE	20 days	Fri 11/22/13	Thu 12/19/13	NA	0 days	No	4	37,14	Fri 11/22/13
11	11	FROM 43 APPROVAL FOR SMITH ROAD ASPHALT	1 day	Mon 11/25/13	Mon 11/25/13	NA	0 days	No	6	18	Mon 11/25/13
12	12	DEMO PRECON PH 1	5 days	Fri 1/24/14	Tue 2/4/14	NA	0 days	No	37	47	Fri 1/24/14
13	13	DEMO PRECON PH 2	5 days	Tue 3/31/15	Mon 4/6/15	NA	0 days	No	38	115	Tue 3/31/15
14	14	UPRR FLAGGER SET UP	20 days	Fri 12/20/13	Mon 1/27/14	NA	0 days	No	4,10	47	Fri 12/20/13
15	**15**	**CDOT Project Duration**	**514 days**	**Mon 11/25/13**	**Tue 3/15/16**	**NA**	**52.6 days**	**Yes**			**Mon 11/25/13**
16	16	**RAILROAD FLAGGING DAYS**	160.58 days	Mon 2/3/14	Thu 12/3/15	NA	50 days	No	22SS	164FF	Mon 2/3/14
17	**17**	**SMITH ROAD WIDENING**	**51 days**	**Tue 11/26/13**	**Wed 4/2/14**	**NA**	**0 days**	**Yes**			**Tue 11/26/13**
18	18	PROJECT SET-UP	1 day	Tue 11/26/13	Tue 11/26/13	NA	0 days	No	7,11,8,9	20,19	Tue 11/26/13
19	19	MOBILIZE	1 day	Wed 11/27/13	Wed 11/27/13	NA	0 days	No	18	20	Wed 11/27/13
20	20	INSTALL BMP'S FOR SWPPP	1 day	Thu 11/28/13	Thu 11/28/13	NA	0 days	No	19,18	21	Thu 11/28/13
21	21	SET UP TRAFFIC CONTROL FOR WIDENING	1 day	Fri 11/29/13	Fri 11/29/13	NA	0 days	No	20	22	Fri 11/29/13
22	22	C-DOT MEETING TO REMOVE SMITH ROAD OFF CRITICAL PATH	1 day	Thu 1/2/14	Thu 1/2/14	NA	0 days	No	21	23FF,24,39,40,16SS	Thu 1/2/14
23	23	WIDEN SMITH ROAD FOR CONSTRUCTION TO NORTH AND SOUITH	14 days	Mon 12/2/13	Wed 4/2/14	NA	0 days	No	22FF	64	Mon 12/2/13
24	**24**	**PHASE 1-I-70 WESTBOUND**	**427.6 days**	**Mon 11/25/13**	**Wed 11/4/15**	**NA**	**0 days**	**Yes**	**22**		**Mon 11/25/13**
25	**25**	**SUBMITTALS**	**248 days**	**Mon 11/25/13**	**Wed 2/11/15**	**NA**	**0 days**	**No**			**Mon 11/25/13**
26	26	PHASE #1 GIRDER SHOP DRAWING AND C-DOT REVIEW	40 days	Mon 11/25/13	Fri 2/7/14	NA	0 days	No	6	70FS-10 days	Mon 11/25/13
27	27	PHASE #1 REBAR SHOP DRAWINGS AND C-DOT REVIEW	40 days	Tue 1/7/14	Thu 3/13/14	NA	0 days	No	6	61	Tue 1/7/14
28	28	PHASE #1 MSE WALL SHOP DRAWINGS AND C-DOT REVIEW	27 days	Tue 1/7/14	Wed 4/16/14	NA	0 days	No	6	83	Tue 1/7/14
29	29	PHASE #1 GRS FABRIC SUBMITTAL AND C-DOT REVIEW	30 days	Mon 12/16/13	Wed 2/26/14	NA	0 days	No	6	78	Mon 12/16/13
30	30	PHASE #1 GIRDER BEARING DEVICE SHOP DRAWINGS AND C-DOT REVIEW	40 days	Tue 1/7/14	Mon 3/10/14	NA	0 days	No	6	68	Tue 1/7/14
31	31	PHASE #1 OVERHEAD SIGN STRUCTURES SHOP DRAWINGS AMD C-DOT REVIEW	40 days	Mon 11/25/13	Fri 2/7/14	NA	0 days	No	6	95	Mon 11/25/13
32	32	SAFETY CRITICAL WORK (SCW) PHASE #1 AND #2 FOR DRIVING H-PILE AND SHEET PILE SUBMITTAL AND C-DOT REVIEW	15 days	Mon 1/6/14	Wed 1/29/14	NA	0 days	No	6	60	Mon 1/6/14
33	33	SCW PHASE #1 AND #2 FOR OVERHEAD BRIDGE WORK SUBMITTAL AND C-DOT REVIEW	15 days	Mon 3/17/14	Fri 4/4/14	NA	0 days	No	6	70,36	Mon 3/17/14
34	34	SCW PHASE #1 AND #2 FOR EXCAVATION AND EMBANKMENT SUBMITTAL AND C-DOT REVIEW	15 days	Mon 1/13/14	Wed 3/5/14	NA	0 days	No	6	52	Mon 1/13/14
35	35	SCW PHASE #1 SHORING/FW SUBMIT & C-DOT REVIEW	30 days	Mon 11/25/13	Fri 2/14/14	NA	0 days	No	6	55	Mon 11/25/13
36	36	SCW PHASE #1 AND #2 OH STR & GIRDER SUBMIT & C-DOT REVIEW	28 days	Wed 4/9/14	Mon 6/9/14	NA	0 days	No	33	70,137	Wed 4/9/14
37	37	SCW PHASE #1 DEMO PLAN SUBMITTAL AND C-DOT REVIEW	15 days	Fri 12/20/13	Fri 1/24/14	NA	0 days	No	6,4,10	47,12	Fri 12/20/13
38	38	SCW PHASE #2 DEMO PLAN SUBMITTAL AND C-DOT REVIEW	28 days	Mon 1/5/15	Wed 2/11/15	NA	0 days	No	70	115,13	Mon 1/5/15
39	39	SET UP TRAFFIC CONTROL I-70 PHASE 1	4 days	Tue 1/7/14	Fri 1/10/14	NA	0 days	No	22	41	Tue 1/7/14
40	40	INSTALL BMP'S FOR I70 PHASE 1-WESTBOUND	2 days	Tue 1/7/14	Wed 1/8/14	NA	0 days	No	22	41	Tue 1/7/14
41	41	EARTHWORK FOR PHASE 1 CROSSOVERS	2 days	Mon 1/13/14	Tue 1/14/14	NA	0 days	No	40,39	42	Mon 1/13/14
42	42	FINE GRADE FOR PAVING PHASE 1 CROSSOVERS	1 day	Wed 1/15/14	Wed 1/15/14	NA	0 days	No	41	43	Wed 1/15/14
43	43	PAVE PHASE 1 CROSSOVERS	7 days	Thu 1/16/14	Wed 1/29/14	NA	0 days	No	42	44	Thu 1/16/14
44	44	TEMP STRIPING FOR I-70 PHASE 1	3 days	Thu 1/30/14	Tue 2/4/14	NA	0 days	No	43	45,50	Thu 1/30/14
45	45	INSTALL TEMP BARRIER 14,000+ LF PHASE 1	5 days	Wed 2/5/14	Thu 2/13/14	NA	0 days	No	44	46,47	Wed 2/5/14
46	46	REMOVALS AND CLEAR & GRUB I-70 WESTBOUND PHASE 1	5 days	Mon 2/17/14	Tue 3/4/14	NA	0 days	No	45	52	Mon 2/17/14
47	47	REMOVE BRIDGE PHASE 1 WESTBOUND	18 days	Mon 3/31/14	Wed 4/30/14	NA	0 days	No	45,37,14,12	64,58,62	Mon 3/31/14
48	48	EXCAVATE FOR WALL REMOVAL WB	3 days	Tue 7/22/14	Thu 7/24/14	NA	0 days	No	57	52	Tue 7/22/14
49	49	REMOVE LOWER WALL WB	4 days	Thu 7/3/14	Thu 7/10/14	NA	0 days	No	58	52	Thu 7/3/14
50	50	REMOVE ASPHALT PAVING (33,631 SY) WB	10 days	Tue 2/18/14	Tue 4/1/14	NA	0 days	No	44	51	Tue 2/18/14
51	51	REMOVE CONCRETE PAVING (18,128 SY) WB	10 days	Thu 3/13/14	Wed 3/26/14	NA	0 days	No	50	52	Thu 3/13/14
52	52	EXCAVATION AND EMBANKMENT I-70 PH 1 WB (WEST OF BRIDGE)	11 days	Thu 3/27/14	Tue 5/20/14	NA	0 days	No	51,49,34,46,48	78,87,53	Thu 3/27/14
53	53	EXCAVATION & EMBANKMENT PH 1 WB (EAST OF BRIDGE)	11 days	Tue 5/20/14	Thu 6/5/14	NA	0 days	No	52	78	Tue 5/20/14
54	54	DEMO AND REPAIRS OF HIGHLINE CANAL BRIDGE PHASE 1	6 days	Thu 12/11/14	Mon 4/6/15	NA	0 days	No	88	90	Thu 12/11/14
55	55	SHORING AREA A-1 WESTBOUND I-70 BRIDGE WB	6 days	Tue 7/22/14	Mon 8/4/14	NA	0 days	No	57,35	86	Tue 7/22/14
56	56	SHORING AREA A-2 WESTBOUND I-70 BRIDGE WB	6 days	Fri 6/20/14	Mon 6/30/14	NA	0 days	No	58	78	Fri 6/20/14
57	57	SHEET PILE WALL WB ABUTMENT 1	15 days	Fri 6/20/14	Mon 7/21/14	NA	0 days	No	58	55,60,48	Fri 6/20/14
58	58	SHEET PILE WALL WB ABUTMENT 4	15 days	Wed 5/28/14	Thu 7/3/14	NA	0 days	No	47	56,57,49	Wed 5/28/14
59	**59**	**BUILD BRIDGE WESTBOUND I-70**	**362.6 days**	**Tue 4/29/14**	**Wed 11/4/15**	**NA**	**0 days**	**Yes**			**Tue 4/29/14**
60	60	DRIVE H PILE WB	3 days	Wed 7/2/14	Mon 7/7/14	NA	0 days	No	57,32	61	Wed 7/2/14
61	61	F/R/P ABUTMENT SEAT 1 & 4 WB	11 days	Thu 9/25/14	Fri 11/7/14	NA	0 days	No	27,80,60	70,65	Thu 9/25/14
62	62	PIER 3 SHORING CRITICAL PATH IMPACT APPROVAL AND PROCUREMENT	75 days	Tue 4/29/14	Mon 8/25/14	NA	0 days	No	47	63	Tue 4/29/14
63	63	PIER 3 SHORING INSTALLATION ESTIMATED DURATION (NO DESIGN)	10 days	Tue 8/26/14	Thu 9/11/14	NA	0 days	No	62	64	Tue 8/26/14
64	64	DRILLED CAISSONS (BOTH PIERS WB)	7 days	Tue 8/5/14	Tue 9/16/14	NA	0 days	No	47,23,63	65	Tue 8/5/14
65	65	PIER 2- CRASH WALL WB F/P/S	7 days	Mon 8/11/14	Tue 9/23/14	NA	0 days	No	64,61	66,68	Mon 8/11/14
66	66	PIER 3- CRASH WALL WB F/P/S	7 days	Mon 10/13/14	Wed 10/22/14	NA	0 days	No	65	67	Mon 10/13/14
67	67	PIER 3 SHORING REMOVAL ESTIMATED DURATION (NO DESIGN)	6 days	Wed 10/22/14	Tue 11/4/14	NA	0 days	No	66	69	Wed 10/22/14
68	68	PIER 2- COLUMNS AND CAPS WB F/P/S	5 days	Tue 9/23/14	Fri 10/3/14	NA	0 days	No	30,65	69	Tue 9/23/14
69	69	PIER 3- COLUMNS AND CAPS WB F/P/S	5 days	Tue 11/4/14	Mon 11/10/14	NA	0 days	No	68,67	70	Tue 11/4/14
70	70	GIRDER ERECTION WB	11 days	Mon 11/10/14	Fri 12/12/14	NA	0 days	No	61,36,69,26FS-10 days,	71,38	Mon 11/10/14
71	71	ABUTMENT & PIER DIAPHRAGMS WB F/P/S	12 days	Fri 12/12/14	Tue 2/3/15	NA	0 days	No	70	72	Fri 12/12/14
72	72	DECK & OVERHANGS WB	12 days	Wed 1/14/15	Wed 2/11/15	NA	0 days	No	71	73,76,75	Wed 1/14/15
73	73	INSTALL BARRIER PHASE 1 WEST OF BRIDGE	8 days	Mon 3/2/15	Fri 3/13/15	NA	0 days	No	72	77,74	Mon 3/2/15
74	74	INSTALL BARRIER PHASE 1 EAST OF BRIDGE	5 days	Mon 3/16/15	Mon 3/23/15	NA	0 days	No	73	77	Mon 3/16/15
75	75	APPROACHES WB F/P/S	10 days	Mon 3/2/15	Mon 4/6/15	NA	0 days	No	72	77	Mon 3/2/15
76	76	STRIP AND PATCH WB	8 days	Thu 2/12/15	Tue 4/7/15	NA	0 days	No	72	77,92	Thu 2/12/15
77	77	PAVEMENT TIE IN AT BRIDGES WB	3 days	Tue 4/7/15	Fri 5/1/15	NA	0 days	No	76,88,75,73,74	95	Tue 4/7/15
78	78	GRS ABUTMENT CONSTRUCTION PHASE 1 LOWER	10 days	Tue 7/22/14	Thu 8/14/14	NA	0 days	No	52,53,29,56	79SS,80	Tue 7/22/14
79	79	3RD PARTY VENDOR EQUIPMENT INSTALL AND MONITOR GRS PHASE 1 LOWER	10 days	Tue 7/22/14	Thu 8/14/14	NA	0 days	No	78SS	83	Tue 7/22/14
80	80	GRS ABUTMENT CONSTRUCTION PH 1 UPPER	10 days	Thu 8/14/14	Tue 9/30/14	NA	0 days	No	78	83,82SS,81SS,85,61	Thu 8/14/14
81	81	3RD PARTY VENDOR EQUIPMENT INSTALL AND MONITOR GRS PHASE 1 UPPER	10 days	Thu 8/14/14	Tue 9/30/14	NA	0 days	No	80SS	83	Thu 8/14/14

Project: CDOT I70 Tower to
Colfax 11.30.15 Status 1
Date : Friday 11/30/15

Task	▬	Baseline	▨	Rolled Up Task	▬	Rolled Up Baseline	▨	External Tasks	▬	Inactive Milestone	◇	Manual Summary Rollup	▬	Deadline	⇩
Task Progress	▭	Milestone	◆	Rolled Up Critical Task	▬	Rolled Up Baseline Milestone	◇	Project Summary	▬	Inactive Summary	▬	Manual Summary	▬		
Critical Task	▬	Baseline Milestone	◇	Rolled Up Milestone	◇	Rolled Up Progress	▬	Group By Summary	▬	Manual Task	▬	Start-only	[		
Critical Task Progress	▭	Summary	▬	Baseline Summary	▬	Split	┆	Inactive Task	▭	Duration-only	▬	Finish-only	]		

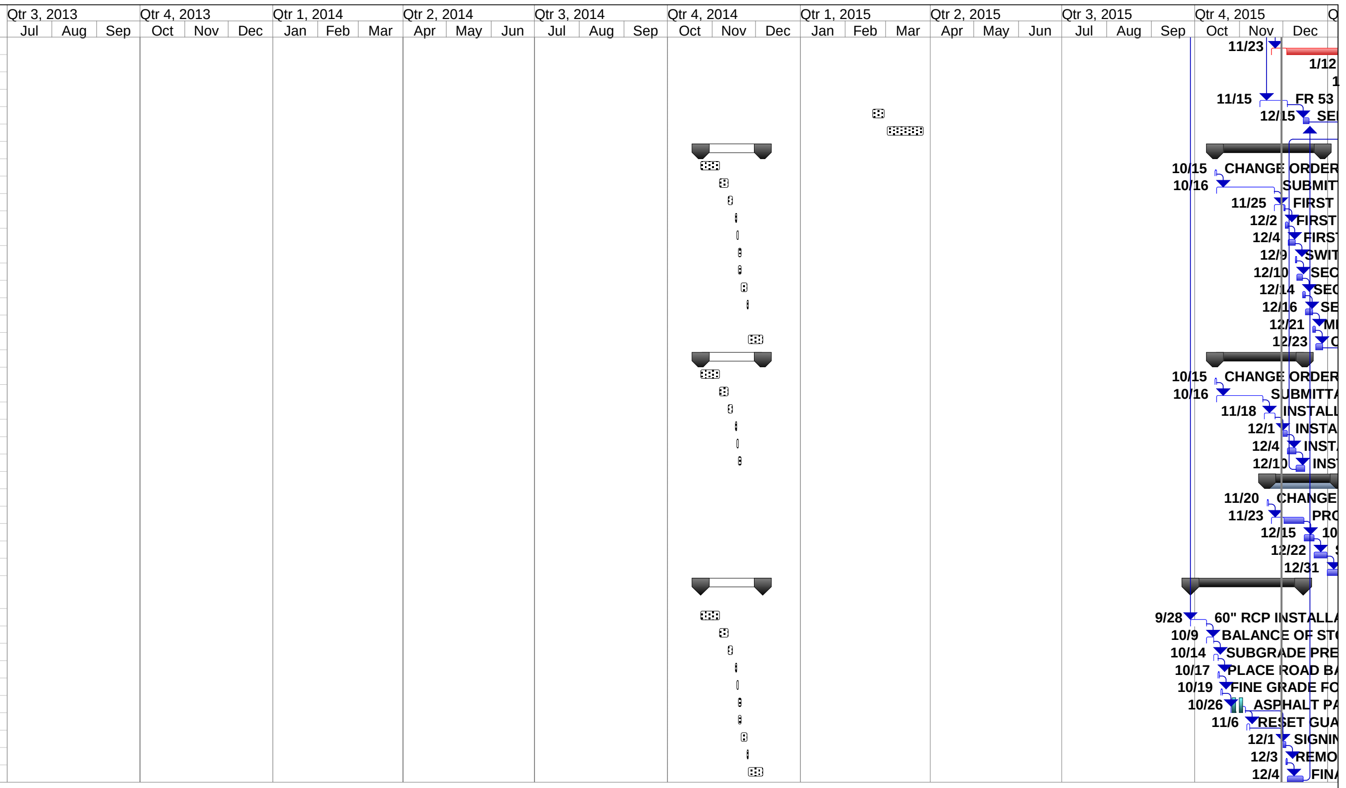
ID	ID	Task Name	Duration	Start	Finish	Constraint Date	Remaining Duration	Critical	Predecessors	Successors	Actual Start
82	82	STORM DRAINAGE/IRRIGATION CANAL WORK I-70 WESTBOUND PHASE 1	10 days	Thu 8/14/14	Thu 8/28/14	NA	0 days	No	80SS	83	Thu 8/14/14
83	83	BLOCK WALL E-17-DG CONSTRUCTION (1,817 SF) PHASE 1	12 days	Thu 8/28/14	Wed 3/11/15	NA	0 days	No	82,80,28,79,81	88	Thu 8/28/14
84	84	BLOCK WALL E-17-DJ CONSTRUCTION (3,421 SF) PHASE 1 LOWER	10 days	Mon 5/19/14	Mon 7/28/14	NA	0 days	No	87	88	Mon 5/19/14
85	85	BLOCK WALL E-17-DJ CONSTRUCTION (3,421 SF) PHASE 1 UPPER	10 days	Mon 3/2/15	Tue 3/17/15	NA	0 days	No	80	94	Mon 3/2/15
86	86	PLACE CLASS 1 FILL (9913 CY) WB	7 days	Thu 8/28/14	Thu 3/5/15	NA	0 days	No	55	89	Thu 8/28/14
87	87	FINE GRADE FOR PAVING (56,457 SY) WB	15 days	Mon 6/30/14	Mon 7/21/14	NA	0 days	No	52	88,84	Mon 6/30/14
88	88	7 3/4" ROLLER COMPACTED CONCRETE PAVING (40,045 SY) WB	10 days	Mon 10/13/14	Thu 1/15/15	NA	0 days	No	87,84,83	89,77,54	Mon 10/13/14
89	89	1" ASPHALT BOND BREAKER (44,475 SY) WB	5 days	Thu 11/20/14	Sat 1/17/15	NA	0 days	No	88,86	90	Thu 11/20/14
90	90	11" PORTLAND CEMENT CONCRETE PAVING WB (WEST OF BRIDGE)	22.55 days	Fri 11/21/14	Wed 1/21/15	NA	0 days	No	89,54	95,91	Fri 11/21/14
91	91	11" PORTLAND CEMENT CONCRETE PAVING (EAST OF BRIDGE)	9 days	Mon 12/22/14	Sat 1/31/15	NA	0 days	No	90	95	Mon 12/22/14
92	92	BRIDGE LIGHTING WB	8 days	Thu 3/12/15	Tue 4/14/15	NA	0 days	No	76		Thu 3/12/15
93	93	BRIDGE COATINGS AND SEALERS WB	4 days	Mon 10/12/15	Wed 11/4/15	NA	0 days	No	139SS	162	Mon 10/12/15
94	94	STRUCTURE E-17-AEK PAVING AND FINISH WORK WB	3 days	Wed 4/22/15	Sat 5/2/15	NA	0 days	No	85	107SS	Wed 4/22/15
95	95	SIGNING/STRIPING AND GUARDRAIL WB	3 days	Fri 4/10/15	Mon 5/4/15	NA	0 days	No	90,77,91,31	96,105,106,98	Fri 4/10/15
96	96	SEEDING AND CLEANUP PHASE 1 I-70	4 days	Tue 4/14/15	Mon 5/11/15	NA	0 days	No	95	107SS	Tue 4/14/15
97	**97**	**PHASE 2-I-70 EASTBOUND**	**514 days**	**Mon 11/25/13**	**Tue 3/15/16**	**NA**	**85.89 days**	**Yes**			**Mon 11/25/13**
98	**98**	**SUBMITTALS**	**336.25 days**	**Mon 11/25/13**	**Tue 6/30/15**	**NA**	**0 days**	**No**	**95**		**Mon 11/25/13**
99	99	PHASE #2 GIRDER SHOP DRAWING AND C-DOT REVIEW	35 days	Mon 4/21/14	Tue 6/17/14	NA	0 days	No	6	137	Mon 4/21/14
100	100	PHASE #2 REBAR SHOP DRAWINGS AND C-DOT REVIEW	35 days	Mon 5/4/15	Tue 6/30/15	NA	0 days	No	6	129	Mon 5/4/15
101	101	PHASE #2 MSE WALL SHOP DRAWINGS AND C-DOT REVIEW	30 days	Wed 3/26/14	Mon 5/19/14	NA	0 days	No	6	150	Wed 3/26/14
102	102	PHASE #2 GRS FABRIC SUBMITTAL AND C-DOT REVIEW	30 days	Mon 12/16/13	Tue 2/18/14	NA	0 days	No	6	145	Mon 12/16/13
103	103	PHASE #2 GIRDER BEARING DEVICE SHOP DRAWINGS AND C-DOT REVIEW	40 days	Tue 10/21/14	Thu 12/18/14	NA	0 days	No	6	135	Tue 10/21/14
104	104	PHASE #2 OVERHEAD SIGN STRUCTURES SHOP DRAWINGS AMD C-DOT REVIEW	40 days	Mon 11/25/13	Fri 2/14/14	NA	0 days	No	6	165	Mon 11/25/13
105	105	SET UP TRAFFIC CONTROL I-70 PHASE 2	3 days	Mon 5/4/15	Mon 5/11/15	NA	0 days	No	95	108	Mon 5/4/15
106	106	INSTALL BMP'S FOR I70 PHASE 2-EASTBOUND	2 days	Mon 5/4/15	Mon 6/1/15	NA	0 days	No	95	107SS	Mon 5/4/15
107	107	RESTRIPE WESTBOUND FOR PHASE 2	1 day	Mon 5/4/15	Wed 5/6/15	NA	0 days	No	106SS,96SS,94SS	109,112	Mon 5/4/15
108	108	EARTHWORK FOR PHASE 2 CROSSOVERS	2 days	Mon 5/11/15	Mon 6/1/15	NA	0 days	No	105	109	Mon 5/11/15
109	109	FINE GRADE FOR PHASE 2 PAVING CROSSOVERS	1 day	Mon 6/1/15	Tue 6/2/15	NA	0 days	No	108,107	110	Mon 6/1/15
110	110	PAVE PHASE 2 CROSSOVERS	1 day	Tue 6/2/15	Wed 6/3/15	NA	0 days	No	109	111	Tue 6/2/15
111	111	TEMP STRIPING FOR I-70 PHASE 2	1 day	Fri 5/15/15	Wed 6/3/15	NA	0 days	No	110	118	Fri 5/15/15
112	112	INSTALL BARRIER-PHASE 2 14,000 LF	5 days	Wed 5/6/15	Tue 6/2/15	NA	0 days	No	107	113	Wed 5/6/15
113	113	TRAFFIC SWITCH	1 day	Thu 5/14/15	Tue 6/2/15	NA	0 days	No	112	114,118,115,156	Thu 5/14/15
114	114	REMOVALS AND CLEAR & GRUB I-70 EASTBOUND PHASE 2	5 days	Tue 6/2/15	Thu 7/2/15	NA	0 days	No	113	119	Tue 6/2/15
115	115	REMOVE BRIDGE PHASE 2	4 days	Tue 6/2/15	Sat 6/6/15	NA	0 days	No	113,38,13	123,131,116	Tue 6/2/15
116	116	EXCAVATE FOR WALL REMOVAL EB	3 days	Sat 6/6/15	Tue 6/9/15	NA	0 days	No	115	117	Sat 6/6/15
117	117	REMOVE LOWER WALL EB	4 days	Tue 6/9/15	Tue 6/16/15	NA	0 days	No	116	132,130	Tue 6/9/15
118	118	REMOVE ASPHALT PAVING (31,466 SY) EB	8 days	Wed 6/3/15	Tue 7/7/15	NA	0 days	No	111,113	119	Wed 6/3/15
119	119	REMOVE CONCRETE PAVING (16,827 SY) EB	8 days	Thu 6/11/15	Tue 8/4/15	NA	0 days	No	118,114	120FS-8 days	Thu 6/11/15
120	120	EXCAVATION AND EMBANKMENT I-70 PHASE 2 EASTBOUND WEST OF BRIDGE	13 days	Thu 6/11/15	Tue 8/4/15	NA	0 days	No	119FS-8 days	149FS-2 days,157,121,125	Thu 6/11/15
121	121	EXCAVATION & EMBANKMENT PH 2 EB EAST OF BRIDGE	12 days	Sat 7/18/15	Mon 8/3/15	NA	0 days	No	120	145,124	Sat 7/18/15
122	122	DEMO AND REPAIRS OF HIGHLINE CANAL BRIDGE PHASE 2	6 days	Thu 10/15/15	Tue 10/27/15	NA	0 days	No	160	161	Thu 10/15/15
123	123	REMOVE SHORING AREA A-1 WESTBOUND I-70 BRIDGE	4 days	Sat 6/6/15	Wed 6/10/15	NA	0 days	No	115		Sat 6/6/15
124	124	REMOVE SHORING AREA A-2 WESTBOUND I-70 BRIDGE	1 day	Mon 8/3/15	Tue 8/4/15	NA	0 days	No	121	149	Mon 8/3/15
125	125	SHEET PILE WALL EASTBOUND ABUTMENT 1	9 days	Sat 7/18/15	Wed 7/29/15	NA	0 days	No	120	126,150	Sat 7/18/15
126	126	SHEET PILE WALL EASTBOUND ABUTMENT 4	9 days	Wed 7/29/15	Tue 8/11/15	NA	0 days	No	125	150,128	Wed 7/29/15
127	**127**	**BUILD BRIDGE EASTBOUND**	**201.25 days**	**Tue 6/2/15**	**Tue 3/15/16**	**NA**	**54.86 days**	**Yes**			**Tue 6/2/15**
128	128	DRIVE H PILE EB	3 days	Tue 8/11/15	Fri 8/14/15	NA	0 days	No	126		Tue 8/11/15
129	129	F/R/P ABUTMENT SEAT 1 & 4 EB	9 days	Sat 8/15/15	Thu 9/3/15	NA	0 days	No	100,146	137	Sat 8/15/15
130	130	PIER 3 SHORING INSTALLATION ESTIMATED DURATION (NO DESIGN)	7 days	Thu 6/18/15	Thu 6/25/15	NA	0 days	No	117	131	Thu 6/18/15
131	131	DRILLED CAISSONS EB	7 days	Mon 6/29/15	Wed 7/8/15	NA	0 days	No	115,130	132	Mon 6/29/15
132	132	PIER 2- CRASH WALL EB F/P/S	7 days	Thu 7/9/15	Thu 7/16/15	NA	0 days	No	117,131	133SS	Thu 7/9/15
133	133	PIER 3- CRASH WALL EB F/P/S	7 days	Thu 7/9/15	Thu 7/16/15	NA	0 days	No	132SS	134	Thu 7/9/15
134	134	PIER 3 SHORING REMOVAL ESTIMATED DURATION (NO DESIGN)	5.25 days	Fri 7/17/15	Thu 7/23/15	NA	0 days	No	133	135	Fri 7/17/15
135	135	PIER 2- COLUMNS AND CAPS EB F/P/S	7 days	Thu 7/23/15	Tue 8/4/15	NA	0 days	No	103,134	136SS	Thu 7/23/15
136	136	PIER 3- COLUMNS AND CAPS EB F/P/S	7 days	Thu 7/23/15	Thu 8/6/15	NA	0 days	No	135SS	137	Thu 7/23/15
137	137	GIRDER ERECTION EB	9 days	Thu 9/3/15	Fri 9/18/15	NA	0 days	No	129,136,99,36	138,199	Thu 9/3/15
138	138	ABUTMENT & PIER DIAPHRAGMS EB F/P/S	10 days	Fri 9/18/15	Thu 10/1/15	NA	0 days	No	137	139,160	Fri 9/18/15
139	139	DECK & OVERHANGS EB	10 days	Fri 10/2/15	Thu 10/15/15	NA	0 days	No	138	140,142,143,93SS	Fri 10/2/15
140	140	INSTALL BARRIER EB WEST OF BRIDGE	5 days	Fri 10/16/15	Mon 10/26/15	NA	0 days	No	139	144,141	Fri 10/16/15
141	141	INSTALL BARRIER EB EAST OF BRIDGE	5 days	Tue 10/27/15	Mon 11/2/15	NA	0 days	No	140	144	Tue 10/27/15
142	142	APPROACHES EB F/P/S	10 days	Fri 10/16/15	Mon 11/2/15	NA	0 days	No	139	144	Fri 10/16/15
143	143	STRIP AND PATCH EB	8 days	Fri 10/16/15	Mon 11/9/15	NA	0 days	No	139	144	Fri 10/16/15
144	144	PAVEMENT TIE IN AT BRIDGES EB	3 days	Tue 11/10/15	Sat 11/14/15	NA	0 days	No	143,140,142,141	165,170	Tue 11/10/15
145	145	GRS ABUTMENT CONSTRUCTION PHASE 2 LOWER	10 days	Mon 8/3/15	Sat 8/15/15	NA	0 days	No	121,102	146SS,147	Mon 8/3/15
146	146	3RD PARTY VENDOR EQUIPMENT INSTALL AND MONITOR GRS PHASE 2 LOWER	10 days	Mon 8/3/15	Sat 8/15/15	NA	0 days	No	145SS	150,129	Mon 8/3/15
147	147	GRS ABUTMENT CONSTRUCTION PHASE 2 UPPER	10 days	Sat 8/15/15	Wed 9/9/15	NA	0 days	No	145	150,148SS,155	Sat 8/15/15
148	148	3RD PARTY VENDOR EQUIPMENT INSTALL AND MONITOR GRS PHASE 2 UPPER	10 days	Sat 8/15/15	Wed 9/9/15	NA	0 days	No	147SS	150	Sat 8/15/15
149	149	STORM DRAINAGE/IRRIGATION CANAL WORK I-70 EASTBOUND PHASE 2	8 days	Tue 8/4/15	Fri 8/14/15	NA	0 days	No	120FS-2 days,124	150	Tue 8/4/15
150	150	BLOCK WALL E-17-DH CONSTRUCTION PHASE 2 LOWER	10 days	Thu 9/10/15	Tue 9/22/15	NA	0 days	No	149,147,126,125,101,146,	151	Thu 9/10/15
151	151	BLOCK WALL E-17-DH CONSTRUCTION PHASE 2 UPPER	10 days	Tue 9/22/15	Mon 10/5/15	NA	0 days	No	150	152	Tue 9/22/15
152	152	BLOCK WALL E-17-DI CONSTRUCTION (1,968 SF) PHASE 2	10 days	Mon 10/5/15	Mon 10/19/15	NA	0 days	No	151	153	Mon 10/5/15
153	153	BLOCK WALL E-17-DK CONSTRUCTION (1,228 SF) PHASE 2	6 days	Mon 10/19/15	Fri 10/30/15	NA	0 days	No	152	154	Mon 10/19/15
154	154	BLOCK WALL E-17-DL CONSTRUCTION (520 SF) PHASE 2	3 days	Fri 10/30/15	Wed 11/4/15	NA	0 days	No	153	165	Fri 10/30/15
155	155	PLACE CLASS 1 FILL (6462 CY) PHASE 2	5 days	Thu 9/10/15	Tue 9/15/15	NA	0 days	No	147	165	Thu 9/10/15
156	156	WEST END PAVING FOR EB TOWER ON RAMP	14 days	Tue 6/2/15	Fri 6/19/15	NA	0 days	No	113	157	Tue 6/2/15
157	157	FINE GRADE FOR PAVING (57,018 SY) EB	15 days	Tue 8/4/15	Fri 9/11/15	NA	0 days	No	120,156	160,158	Tue 8/4/15
158	158	ABC CLASS 6 WEST OF BRIDGE	8 days	Fri 9/11/15	Tue 9/22/15	NA	0 days	No	157	159	Fri 9/11/15
159	159	ABC CLASS 6 EAST OF BRIDGE	8 days	Tue 9/22/15	Fri 10/2/15	NA	0 days	No	158	160	Tue 9/22/15
160	160	11" PORTLAND CEMENT CONCRETE PAVING WEST OF BRIDGE	8 days	Fri 10/2/15	Thu 10/15/15	NA	0 days	No	138,159,157	161,122	Fri 10/2/15
161	161	11" PORTLAND CEMENT CONCRETE PAVING EB EAST OF BRIDGE	9 days	Tue 10/27/15	Fri 11/13/15	NA	0 days	No	160,122	165	Tue 10/27/15
162	162	STRUCTURE E-17-AEJ PAVING AND FINISH WORK EB	6 days	Wed 11/4/15	Wed 12/2/15	NA	1.5 days	No	93	165,164,163	Wed 11/4/15
163	163	BRIDGE LIGHTING EB	6 days	Sat 11/14/15	Thu 12/3/15	NA	1.5 days	No	162	172	Sat 11/14/15
164	164	BRIDGE COATINGS AND SEALERS EB	5 days	Wed 10/28/15	Thu 12/3/15	NA	1.25 days	No	162,16FF	172	Wed 10/28/15
165	165	SIGNING/STRIPING AND GUARDRAIL EB	5 days	Sun 11/15/15	Tue 12/8/15	NA	3.75 days	No	162,144,154,155,161,104		Sun 11/15/15
166	166	TL-4 CABLE BARRIER CHANGE ORDER APPROVAL	1 day	Fri 11/20/15	Fri 11/20/15	NA	0 days	No		167	Fri 11/20/15



Project: CDOT I70 Tower to Colfax 11.30.15 Status 1
Date : Friday 11/30/15

Task	Baseline	Rolled Up Task	Rolled Up Baseline	External Tasks	Inactive Milestone ◇	Manual Summary Rollup	Deadline ⇩
Task Progress	Milestone ◆	Rolled Up Critical Task	Rolled Up Baseline Milestone ◇	Project Summary	Inactive Summary	Manual Summary	
Critical Task	Baseline Milestone ◇	Rolled Up Milestone ◇	Rolled Up Progress	Group By Summary	Manual Task	Start-only [	
Critical Task Progress	Summary	Baseline Summary	Split	Inactive Task	Duration-only	Finish-only]	

ID	ID	Task Name	Duration	Start	Finish	Constraint Date	Remaining Duration	Critical	Predecessors	Successors	Actual Start
167	167	TL-4 CABLE BARRIER MATERIAL PROCUREMENT	30 days	Mon 11/23/15	Tue 1/12/16	NA	24.9 days	Yes	166	168	Mon 11/23/15
168	168	TL-4 CABLE BARRIER EAST	12 days	Tue 1/12/16	Thu 1/28/16	NA	12 days	Yes	167	169	NA
169	169	TL-4 CABLE BARRIER WEST	12 days	Thu 1/28/16	Mon 2/15/16	NA	12 days	Yes	168	172	NA
170	170	FR 53 - PAHSE 1 TYPE C INLET	10 days	Sun 11/15/15	Thu 12/3/15	NA	0 days	No	144	171	Sun 11/15/15
171	171	SEEDING AND CLEANUP PHASE 2- I-70	4 days	Tue 12/15/15	Fri 12/18/15	NA	4 days	No	208,170	172	NA
172	172	PUNCHLIST & FINAL ACCEPTANCE ALL	21.5 days	Mon 2/15/16	Tue 3/15/16	NA	21.5 days	Yes	171,163,164,191SS,184,1		NA
173	**173**	**COLFAX BRIDGE EXPANSION JOINT REPLACMENT**	**43.5 days**	**Thu 10/15/15**	**Mon 12/28/15**	**NA**	**16.81 days**	**No**			**Thu 10/15/15**
174	174	CHANGE ORDER APPROVAL	1 day	Thu 10/15/15	Thu 10/15/15	NA	0 days	No		175	Thu 10/15/15
175	175	SUBMITTALS AND PROCURMENT OF MATERIALS	25 days	Fri 10/16/15	Tue 11/24/15	NA	0 days	No	174	176	Fri 10/16/15
176	176	FIRST HALF: TRAFFIC CONTROL/SAWCUT/REMOVALS	2 days	Wed 11/25/15	Wed 12/2/15	NA	1 day	No	175	177	Wed 11/25/15
177	177	FIRST HALF: PREP AND INSTALL EXPANSION JOINT	2 days	Wed 12/2/15	Fri 12/4/15	NA	2 days	No	176	178	NA
178	178	FIRST HALF: POUR EXPANSION JOINT AND CURE	3 days	Fri 12/4/15	Wed 12/9/15	NA	3 days	No	177	179	NA
179	179	SWITCH FROM FIRST HALF TO SECOND HALF	1 day	Wed 12/9/15	Thu 12/10/15	NA	1 day	No	178	180	NA
180	180	SECOND HALF: SAWCUT ANDREMOVALS	2 days	Thu 12/10/15	Mon 12/14/15	NA	2 days	No	179	181	NA
181	181	SECOND HALF: PREP AND INSTALL EXPANSION JOINT	2 days	Mon 12/14/15	Wed 12/16/15	NA	2 days	No	180	182	NA
182	182	SECOND HALF: POUR EXPANSION JOINT AND CURE	3 days	Wed 12/16/15	Mon 12/21/15	NA	3 days	No	181	183	NA
183	183	MILL AND FILL COLFAX BRIDGE DECK	2 days	Mon 12/21/15	Wed 12/23/15	NA	2 days	No	182	184	NA
184	184	OPEN ALL TRAFFIC	1 day	Wed 12/23/15	Mon 12/28/15	NA	1 day	No	183	172	NA
185	**185**	**42 INCH CHAIN LINK FENCE FOR SHEET PILE COPING**	**37 days**	**Thu 10/15/15**	**Tue 12/15/15**	**NA**	**11 days**	**No**			**Thu 10/15/15**
186	186	CHANGE ORDER APPROVAL	1 day	Thu 10/15/15	Thu 10/15/15	NA	0 days	No		187	Thu 10/15/15
187	187	SUBMITTALS AND PROCURMENT OF MATERIALS	20 days	Fri 10/16/15	Mon 11/16/15	NA	0 days	No	186	188	Fri 10/16/15
188	188	INSTALL ABUTMENT 1 WEST	5 days	Wed 11/18/15	Wed 11/25/15	NA	0 days	No	187	189	Wed 11/18/15
189	189	INSTALL ABUTMENT 1 EAST	3 days	Tue 12/1/15	Thu 12/3/15	NA	3 days	No	188	190	NA
190	190	INSTALL ABUTMENT 4 WEST	4 days	Fri 12/4/15	Wed 12/9/15	NA	4 days	No	189	191	NA
191	191	INSTALL ABUTMENT 4 EAST	4 days	Thu 12/10/15	Tue 12/15/15	NA	4 days	No	190	172SS	NA
192	**192**	**TOWER ROAD BRIDGE DECK WORK**	**29 days**	**Fri 11/20/15**	**Fri 1/8/16**	**NA**	**24.75 days**	**No**			**Fri 11/20/15**
193	193	CHANGE ORDER APPROVAL	1 day	Fri 11/20/15	Fri 11/20/15	NA	0 days	No		194	Fri 11/20/15
194	194	PROCURE MATERIALS	13 days	Mon 11/23/15	Tue 12/15/15	NA	9.75 days	No	193	195	Mon 11/23/15
195	195	10" PIPE WORK	5 days	Tue 12/15/15	Tue 12/22/15	NA	5 days	No	194	196	NA
196	196	SIDEWALK AND SLOPE PAVING	5 days	Tue 12/22/15	Thu 12/31/15	NA	5 days	No	195	197	NA
197	197	BRIDGE DECK WORK	5 days	Thu 12/31/15	Fri 1/8/16	NA	5 days	No	196	172	NA
198	**198**	**SMITH ROAD FINAL CONSTRUCTION**	**49 days**	**Mon 9/28/15**	**Mon 12/14/15**	**NA**	**14.41 days**	**No**			**Mon 9/28/15**
199	199	60" RCP INSTALLATION	9 days	Mon 9/28/15	Thu 10/8/15	NA	0 days	No	137	200	Mon 9/28/15
200	200	BALANCE OF STORM SEWER-SMITH ROAD	3 days	Fri 10/9/15	Tue 10/13/15	NA	0 days	No	199	201	Fri 10/9/15
201	201	SUBGRADE PREP	3 days	Wed 10/14/15	Fri 10/16/15	NA	0 days	No	200	202	Wed 10/14/15
202	202	PLACE ROAD BASE	1 day	Sat 10/17/15	Sat 10/17/15	NA	0 days	No	201	203	Sat 10/17/15
203	203	FINE GRADE FOR PAVING PHASE 1 SMITH ROAD	1 day	Mon 10/19/15	Mon 10/19/15	NA	0 days	No	202	204	Mon 10/19/15
204	204	ASPHALT PAVING SMITH ROAD PHASE 1	5 days	Mon 10/26/15	Wed 11/4/15	NA	0 days	No	203	206,205	Mon 10/26/15
205	205	RESET GUARDRAIL	2 days	Fri 11/6/15	Sat 11/7/15	NA	0 days	No	204	206	Fri 11/6/15
206	206	SIGNING AND STRIPING	2 days	Tue 12/1/15	Wed 12/2/15	Mon 11/30/15	2 days	No	204,205	207	NA
207	207	REMOVE PHASE 1 TRAFFIC CONTROL	1 day	Thu 12/3/15	Thu 12/3/15	Mon 11/30/15	1 day	No	206	208	NA
208	208	FINAL CLEANUP FOR SMITH ROAD	7 days	Fri 12/4/15	Mon 12/14/15	Mon 11/30/15	7 days	No	207	171	NA



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Task	▬	Baseline	▨	Rolled Up Task	▬	Rolled Up Baseline	▨	External Tasks	▬	Inactive Milestone	◇	Manual Summary Rollup	▬	Deadline	⇩
Task Progress	▭	Milestone	◆	Rolled Up Critical Task	▬	Rolled Up Baseline Milestone	◇	Project Summary	▬	Inactive Summary	▭	Manual Summary	▬		
Critical Task	▬	Baseline Milestone	◇	Rolled Up Milestone	◇	Rolled Up Progress	▬	Group By Summary	▬	Manual Task	▬	Start-only	[		
Critical Task Progress	▭	Summary	▬	Baseline Summary	▬	Split	┆	Inactive Task	▭	Duration-only	▬	Finish-only	]		

APPENDIX D – DATA ARCHIVE AND TIME PLOTS

EXTERNAL ATTACHMENTS

CD – GRS Instrumentation I-70 Over Smith Road Data

FIGURES

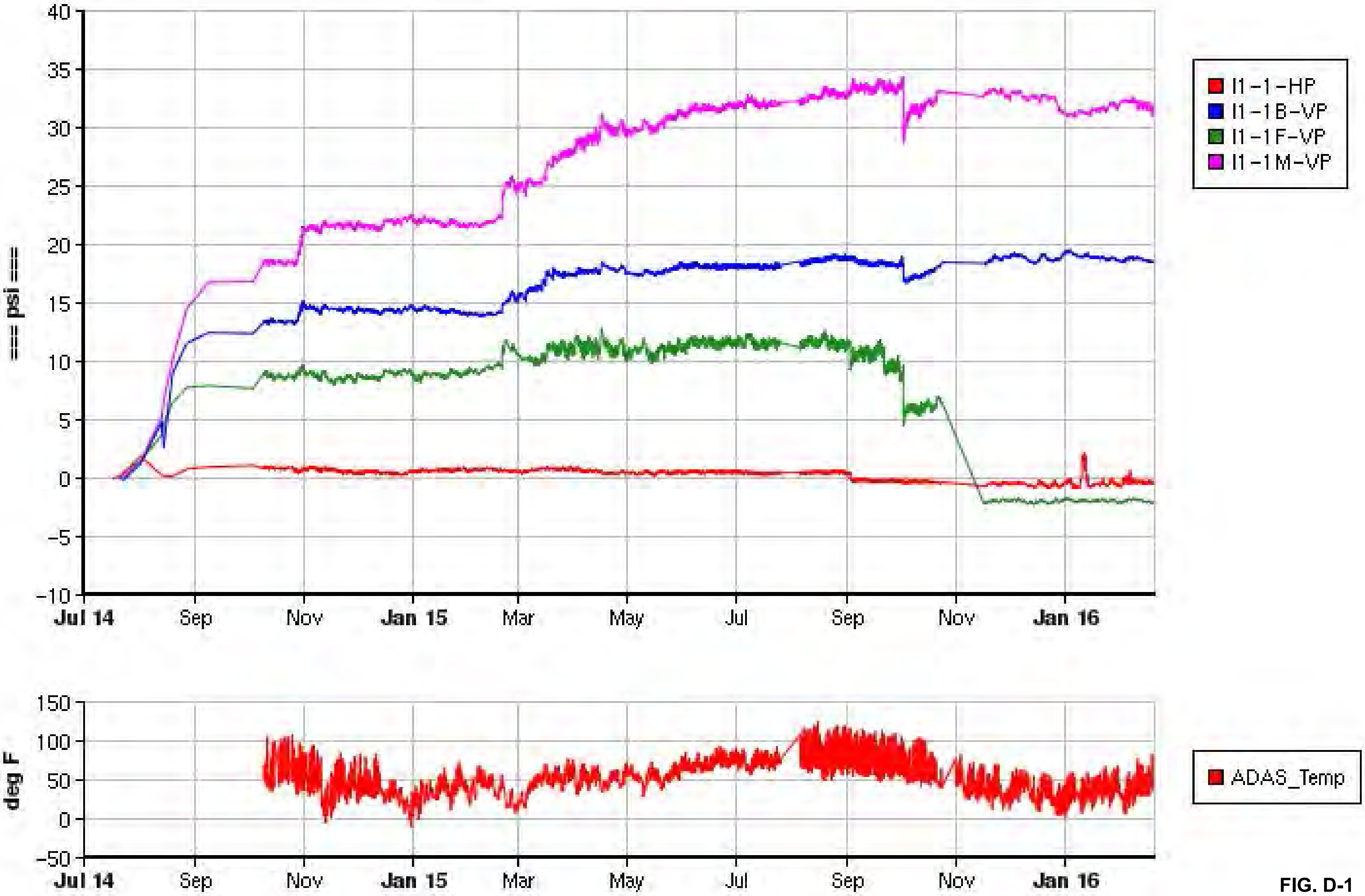

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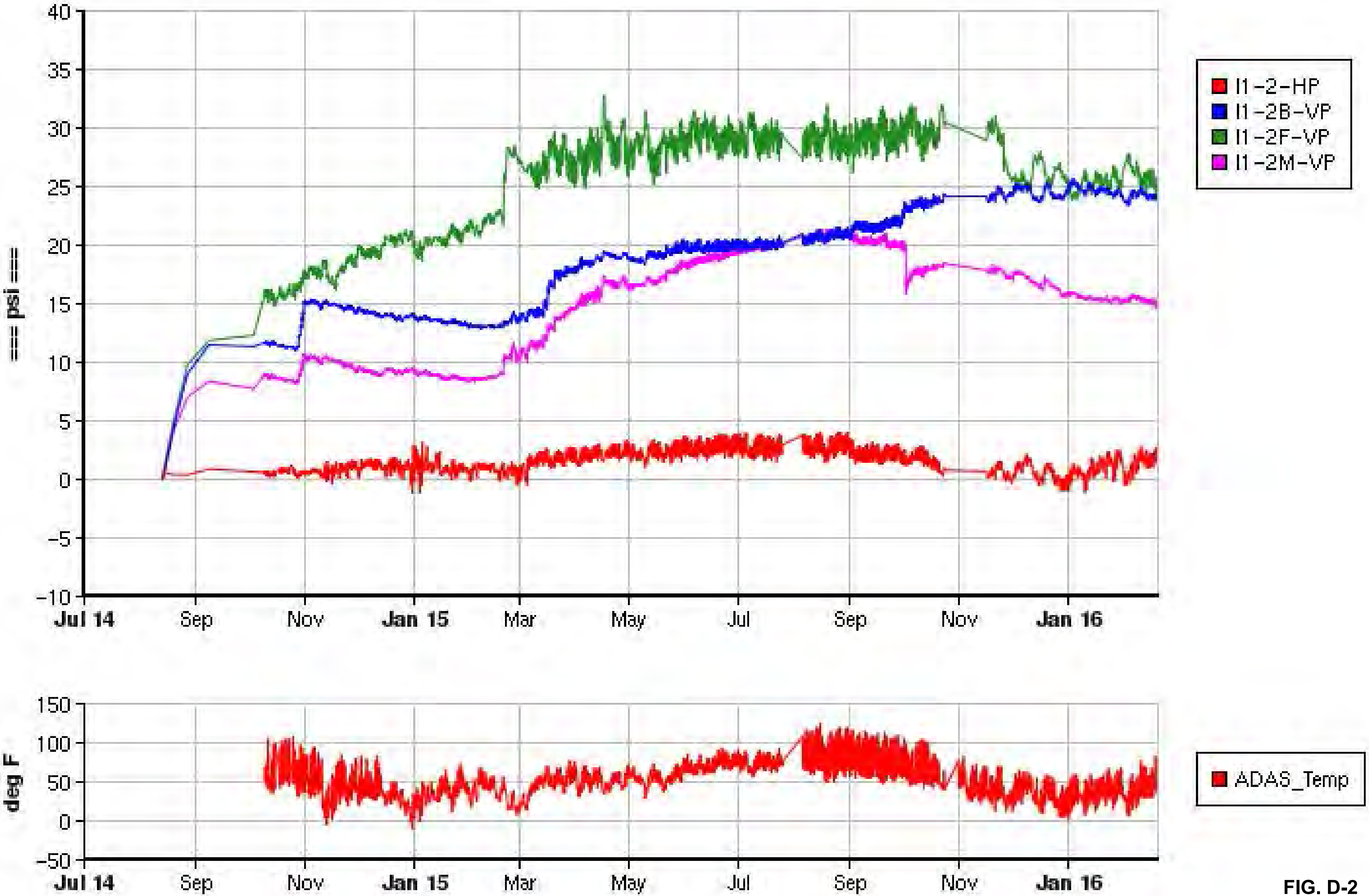
FIG. D-1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Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
🟥 ADAS_Temp

FIG. D-2

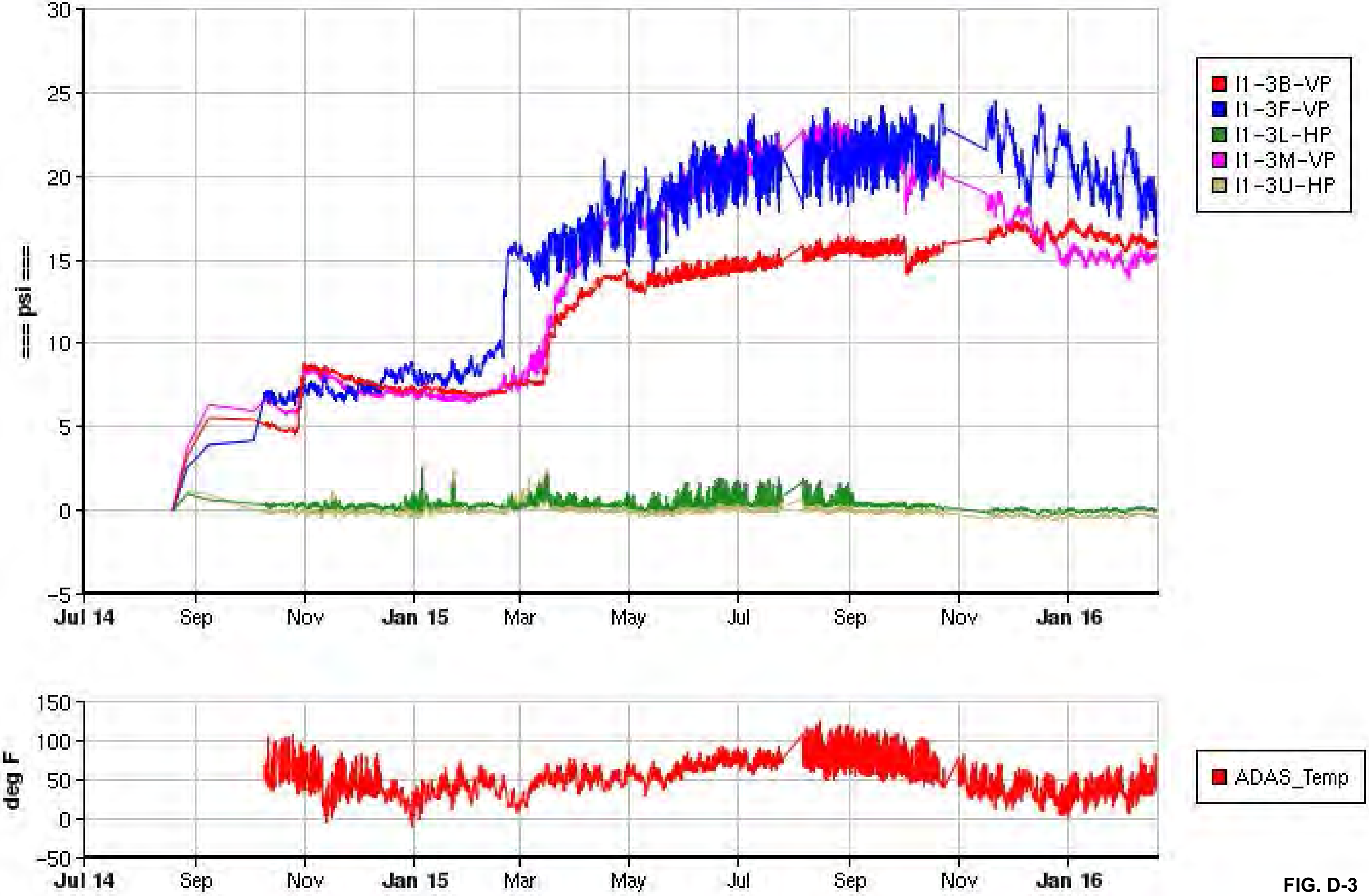

30
25
20
15
10
5
0
−5
=== psi ===
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
I1−3B−VP
I1−3F−VP
I1−3L−HP
I1−3M−VP
I1−3U−HP
150
100
50
0
−50
deg F
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
ADAS_Temp

FIG. D-3

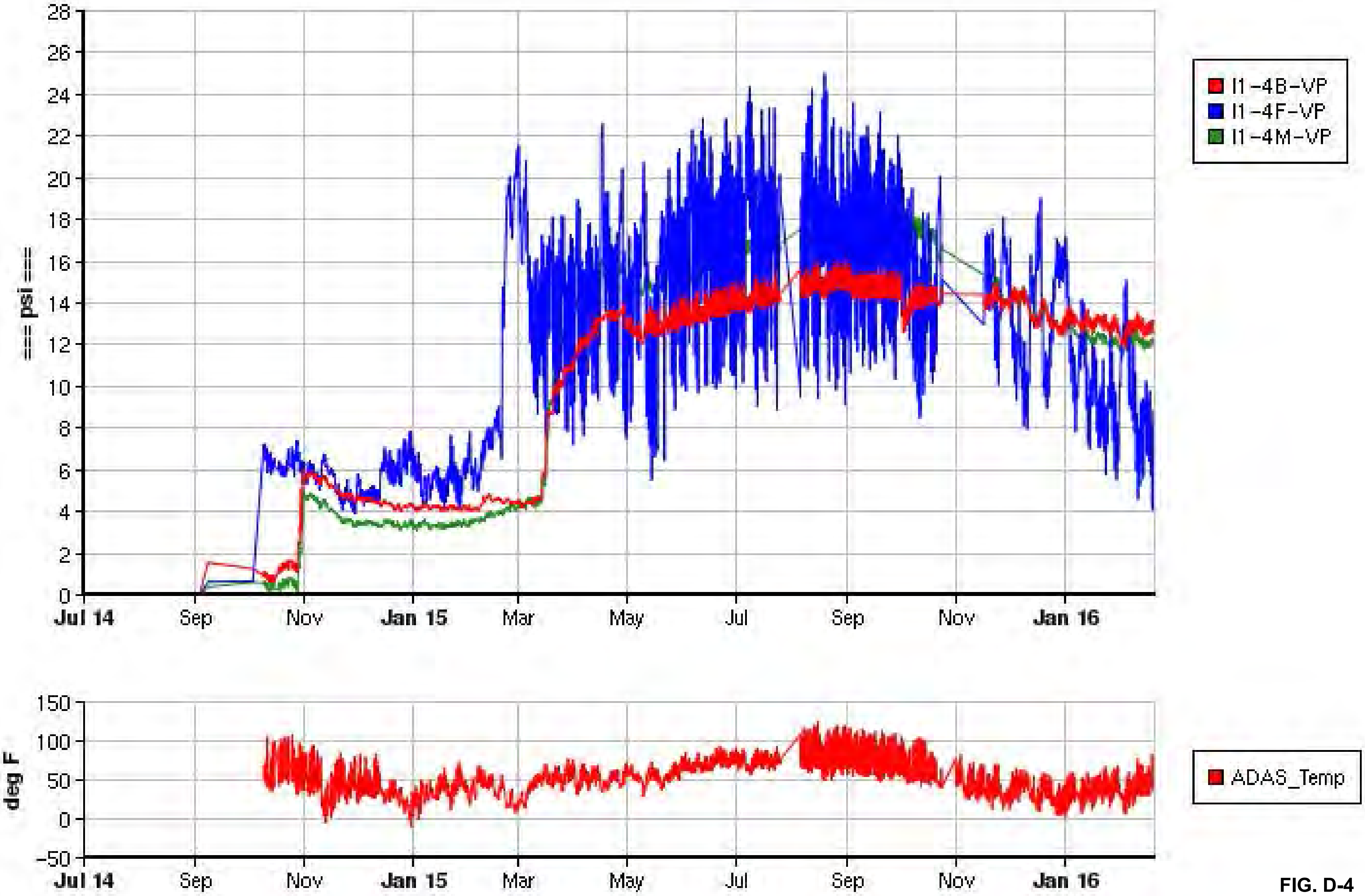

28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
=== psi ===
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
🟥 I1-4B-VP
🟦 I1-4F-VP
🟩 I1-4M-VP
150
100
50
0
-50
deg F
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
🟥 ADAS_Temp

FIG. D-4

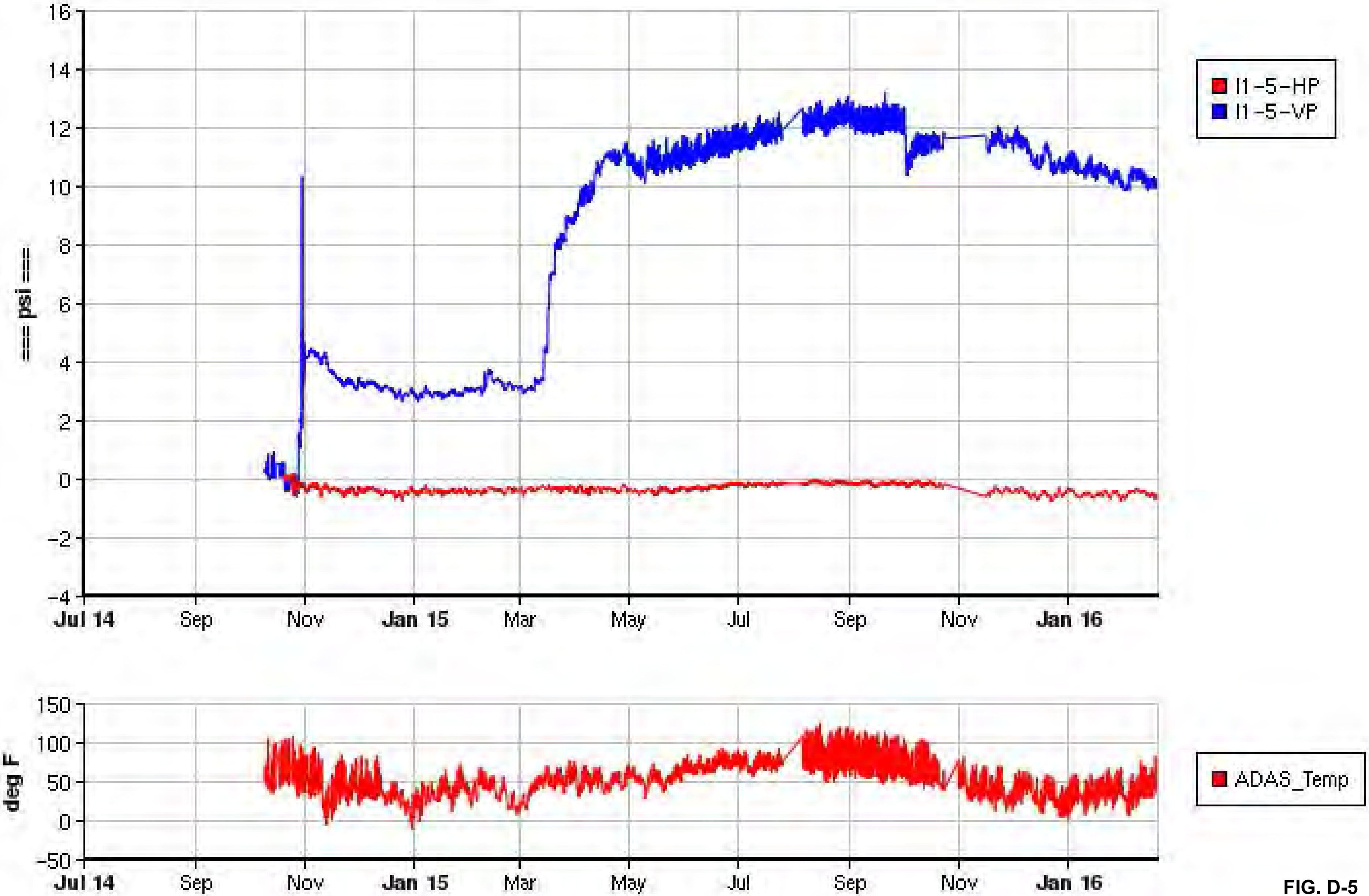

=== psi ===
16
14
12
10
8
6
4
2
0
−2
−4
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
I1−5−HP
I1−5−VP
deg F
150
100
50
0
−50
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
ADAS_Temp

FIG. D-5

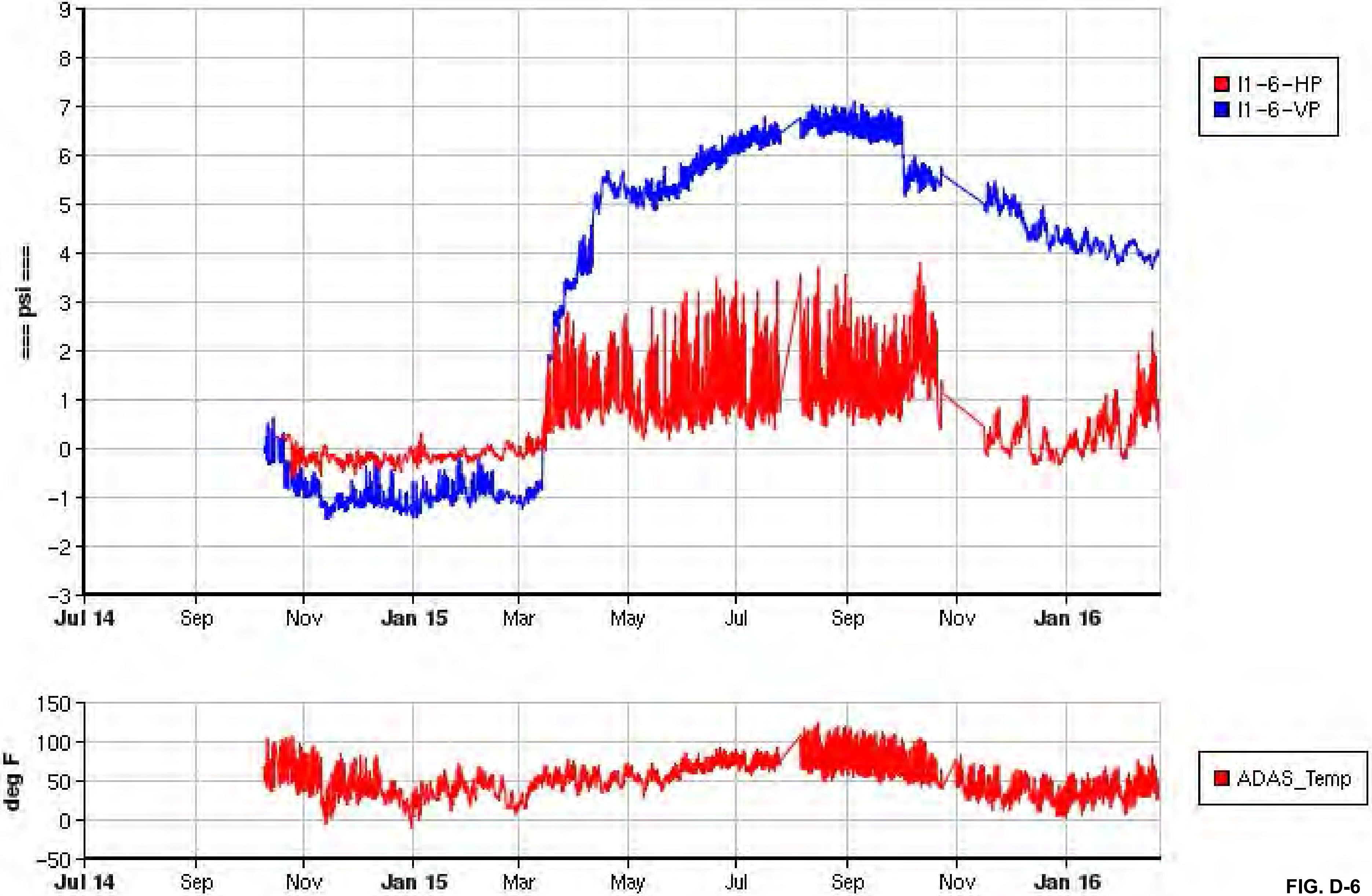

9
8
7
6
5
4
3
2
1
0
−1
−2
−3
=== psi ===
I1−6−HP
I1−6−VP
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
150
100
50
0
−50
deg F
ADAS_Temp
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16

FIG. D-6

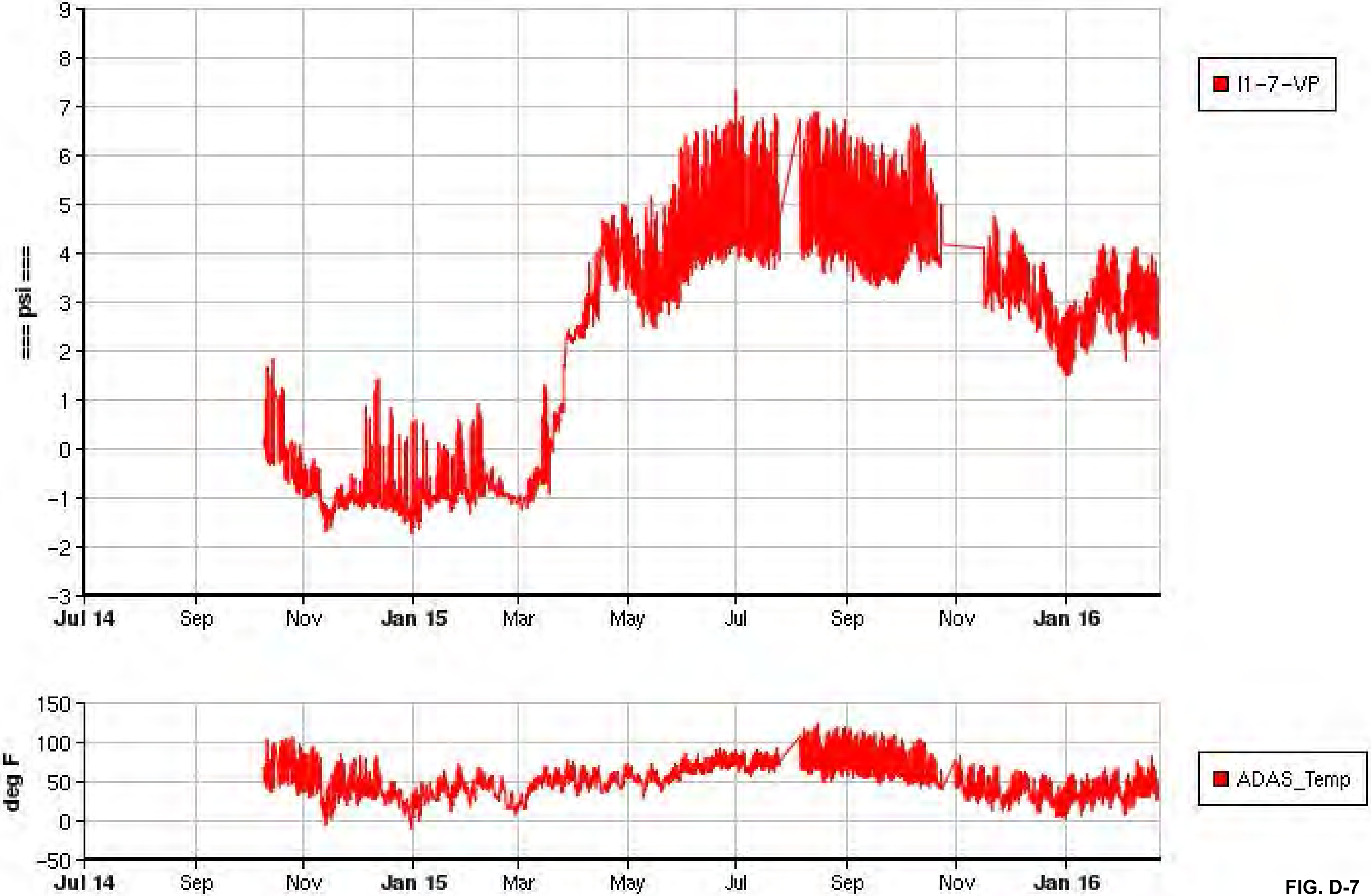

9
8
7
6
5
4
3
2
1
0
−1
−2
−3
=== psi ===
I1−7−VP
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
150
100
50
0
−50
deg F
ADAS_Temp
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16

FIG. D-7

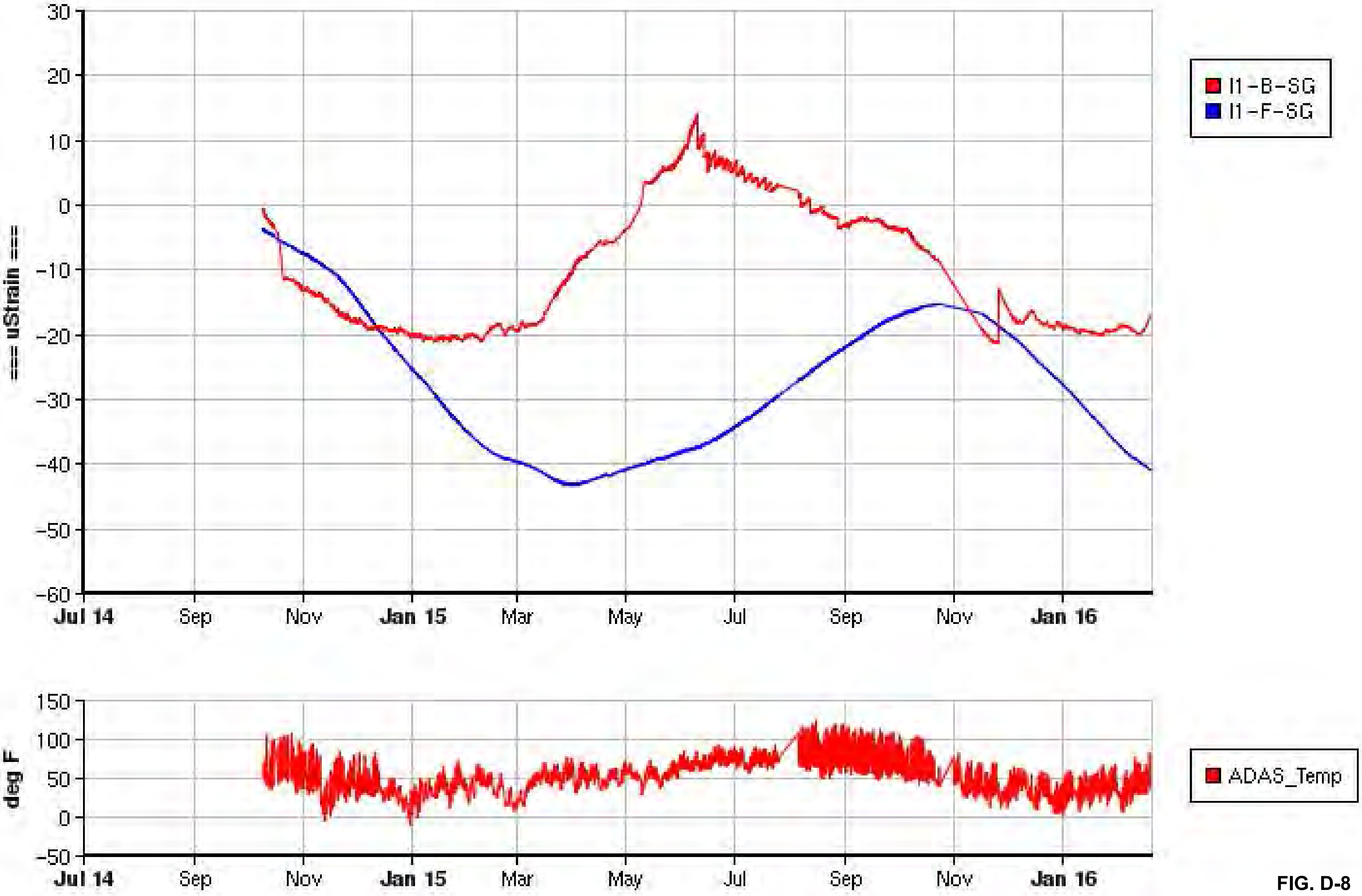

30
20
10
0
-10
-20
-30
-40
-50
-60
=== uStrain ===
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
I1-B-SG
I1-F-SG
150
100
50
0
-50
deg F
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
ADAS_Temp

FIG. D-8

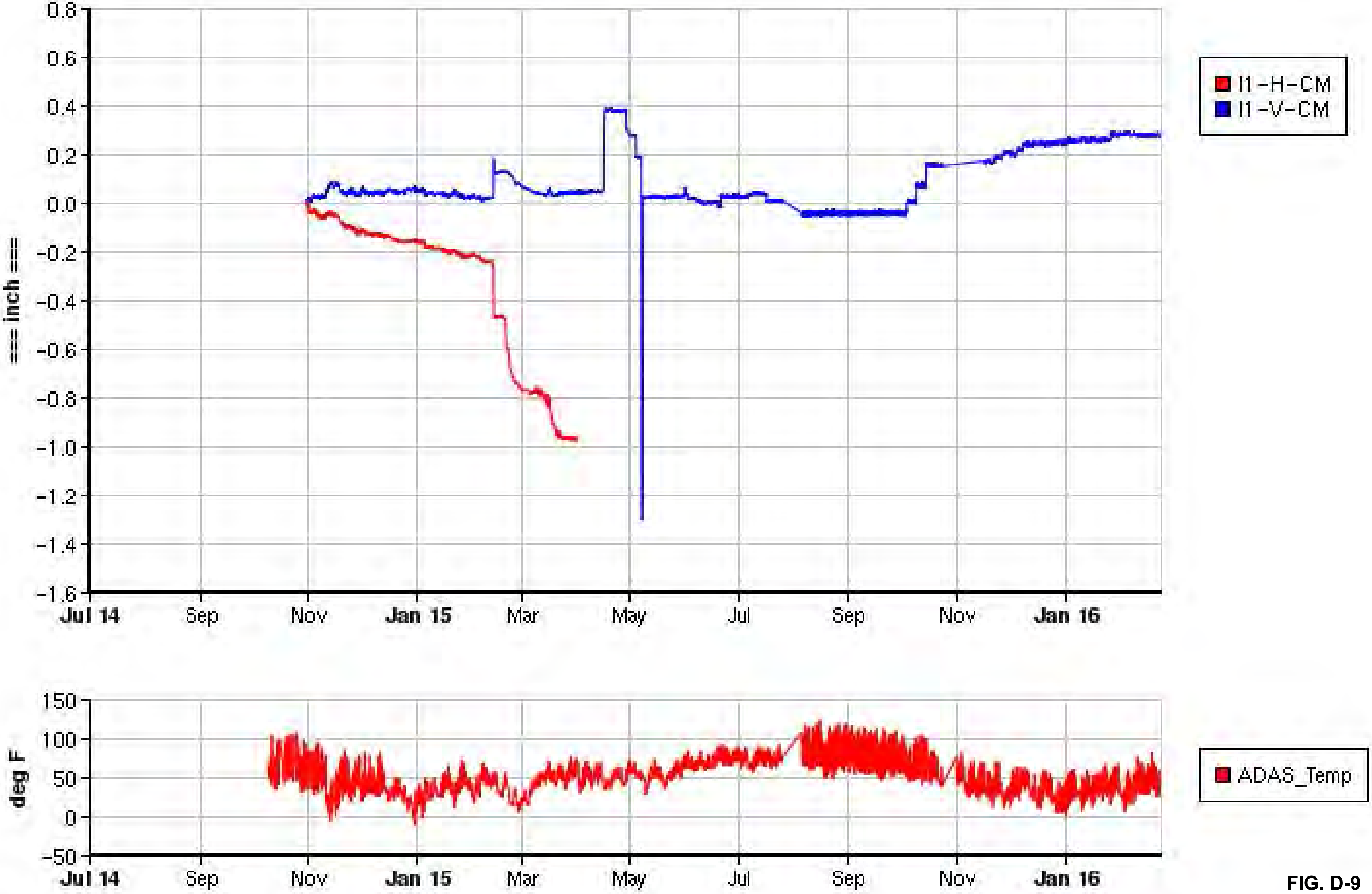
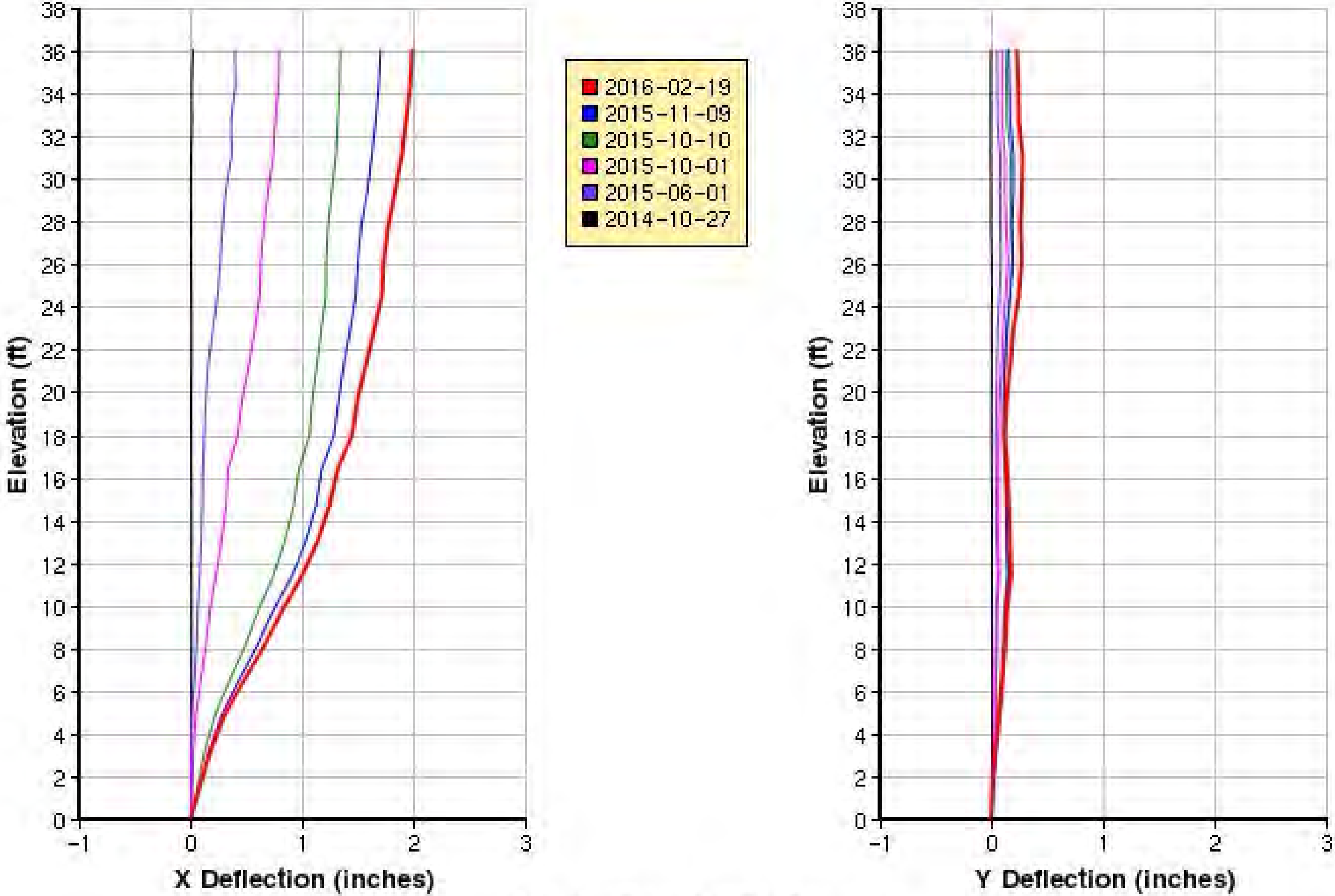

0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
=== inch ===
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
🟥 I1-H-CM
🟦 I1-V-CM
150
100
50
0
-50
deg F
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
🟥 ADAS_Temp

FIG. D-9



Deflection, Daily Average

FIG. D-10

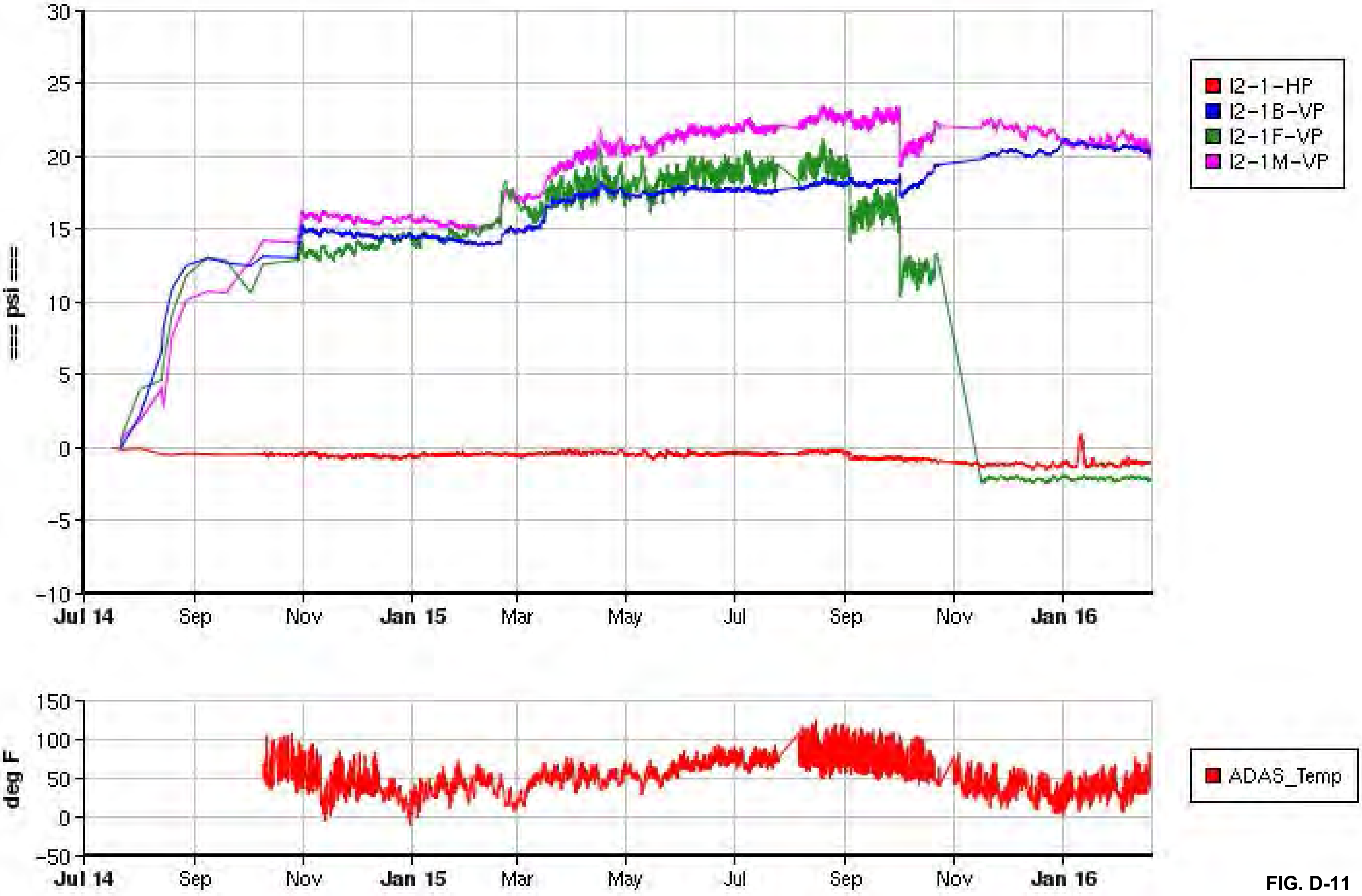

30
25
20
15
10
5
0
-5
-10
=== psi ===
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
🟥 I2-1-HP
🟦 I2-1B-VP
🟩 I2-1F-VP
🟪 I2-1M-VP
150
100
50
0
-50
deg F
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
🟥 ADAS_Temp

FIG. D-11

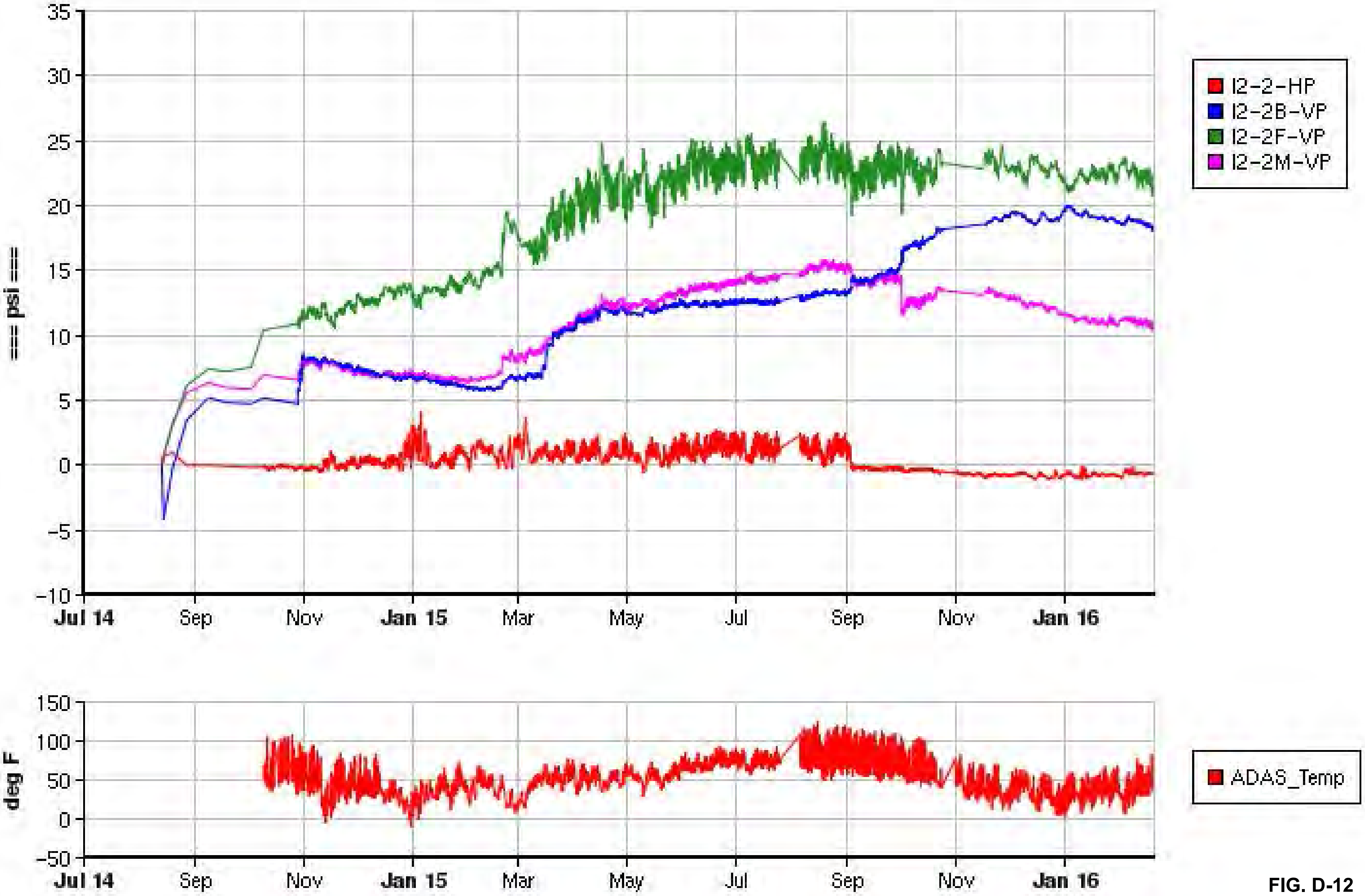

35
30
25
20
15
10
5
0
−5
−10
=== psi ===
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
I2−2−HP
I2−2B−VP
I2−2F−VP
I2−2M−VP
150
100
50
0
−50
deg F
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
ADAS_Temp

FIG. D-12

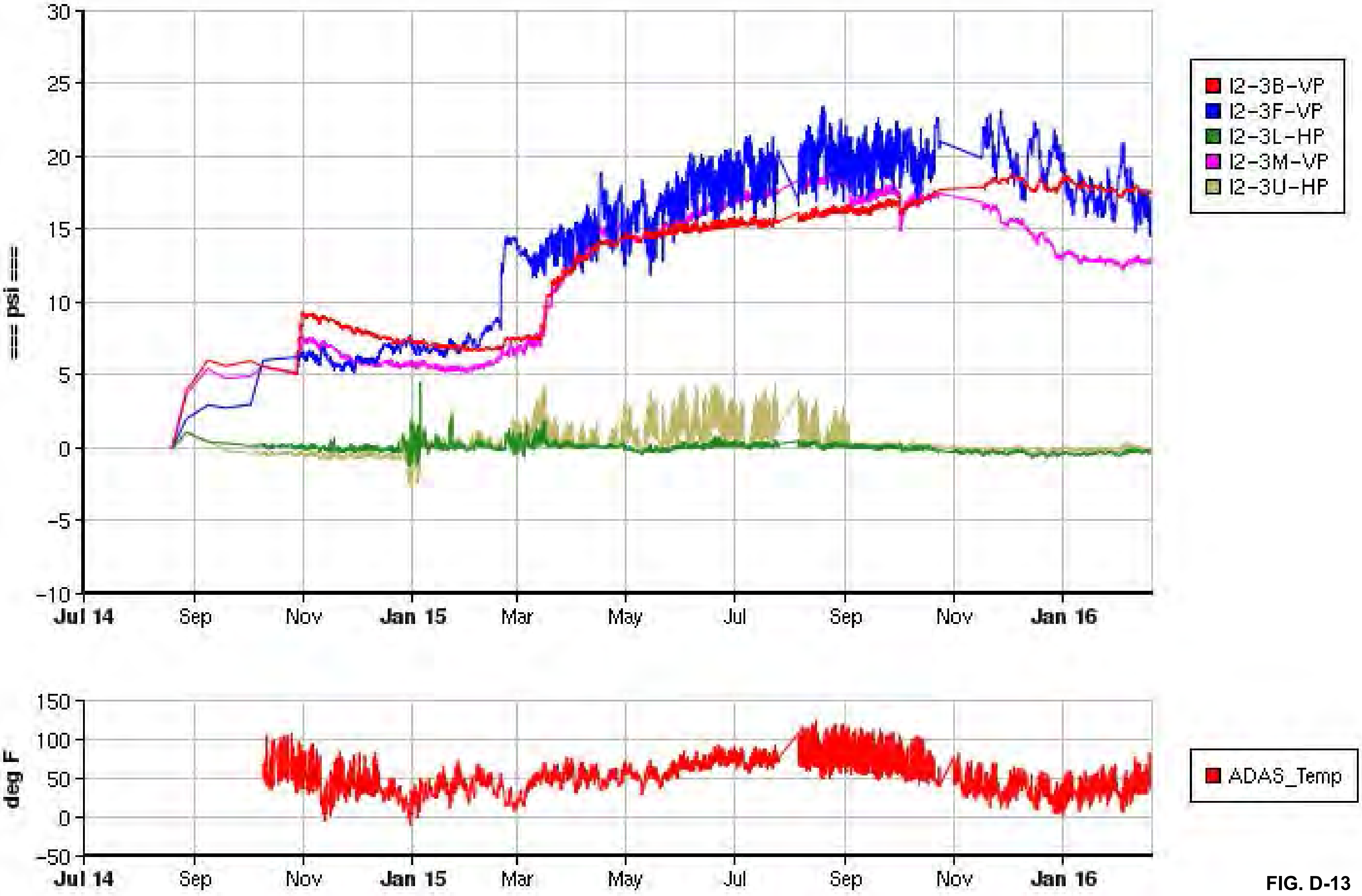

30
25
20
15
10
5
0
-5
-10
=== psi ===
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
🟥 I2-3B-VP
🟦 I2-3F-VP
🟩 I2-3L-HP
🟪 I2-3M-VP
🟨 I2-3U-HP
150
100
50
0
-50
deg F
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
🟥 ADAS_Temp

FIG. D-13

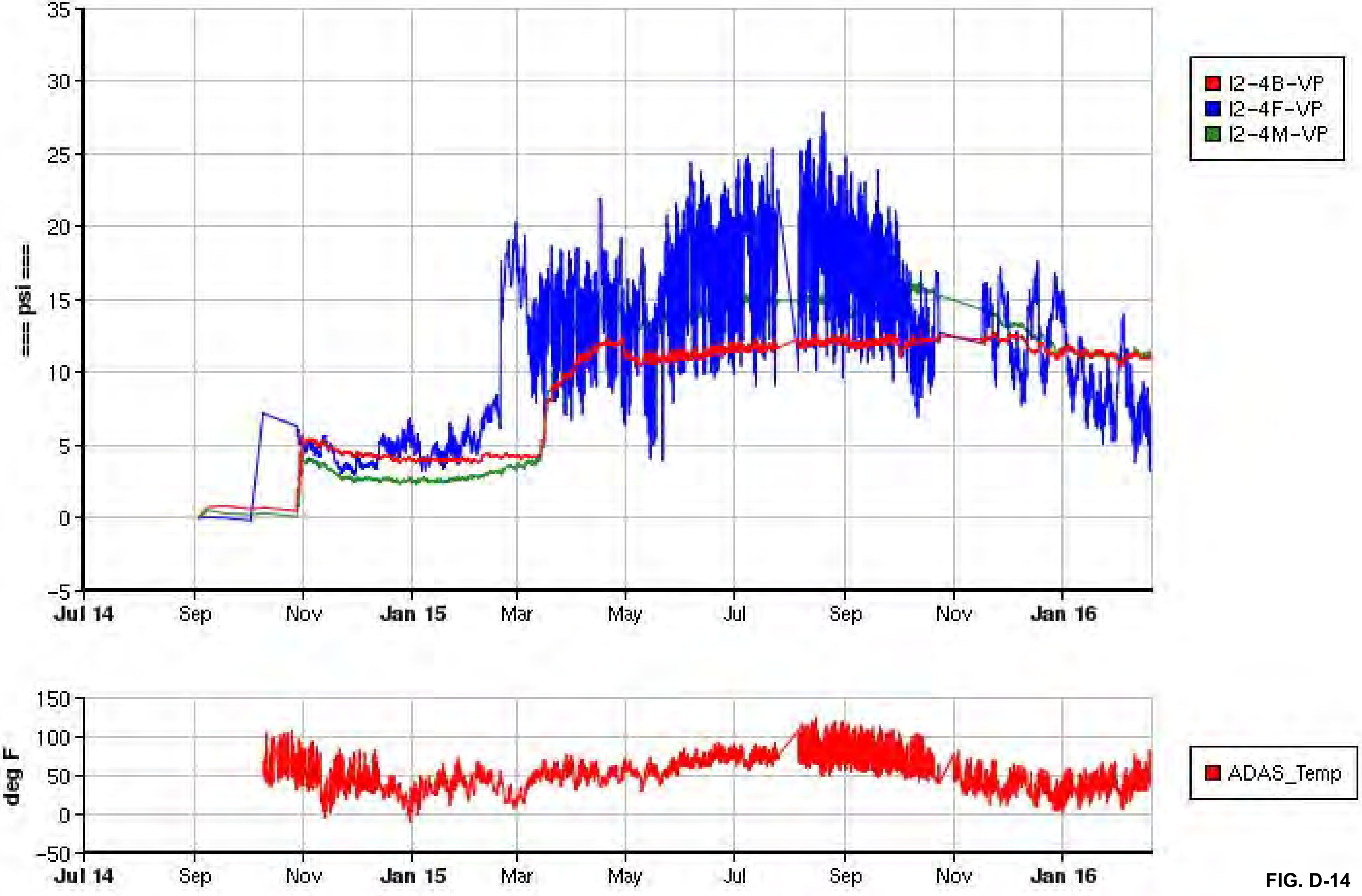

35
30
25
20
15
10
5
0
−5
=== psi ===
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
🟥 I2−4B−VP
🟦 I2−4F−VP
🟩 I2−4M−VP
150
100
50
0
−50
deg F
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
🟥 ADAS_Temp

FIG. D-14

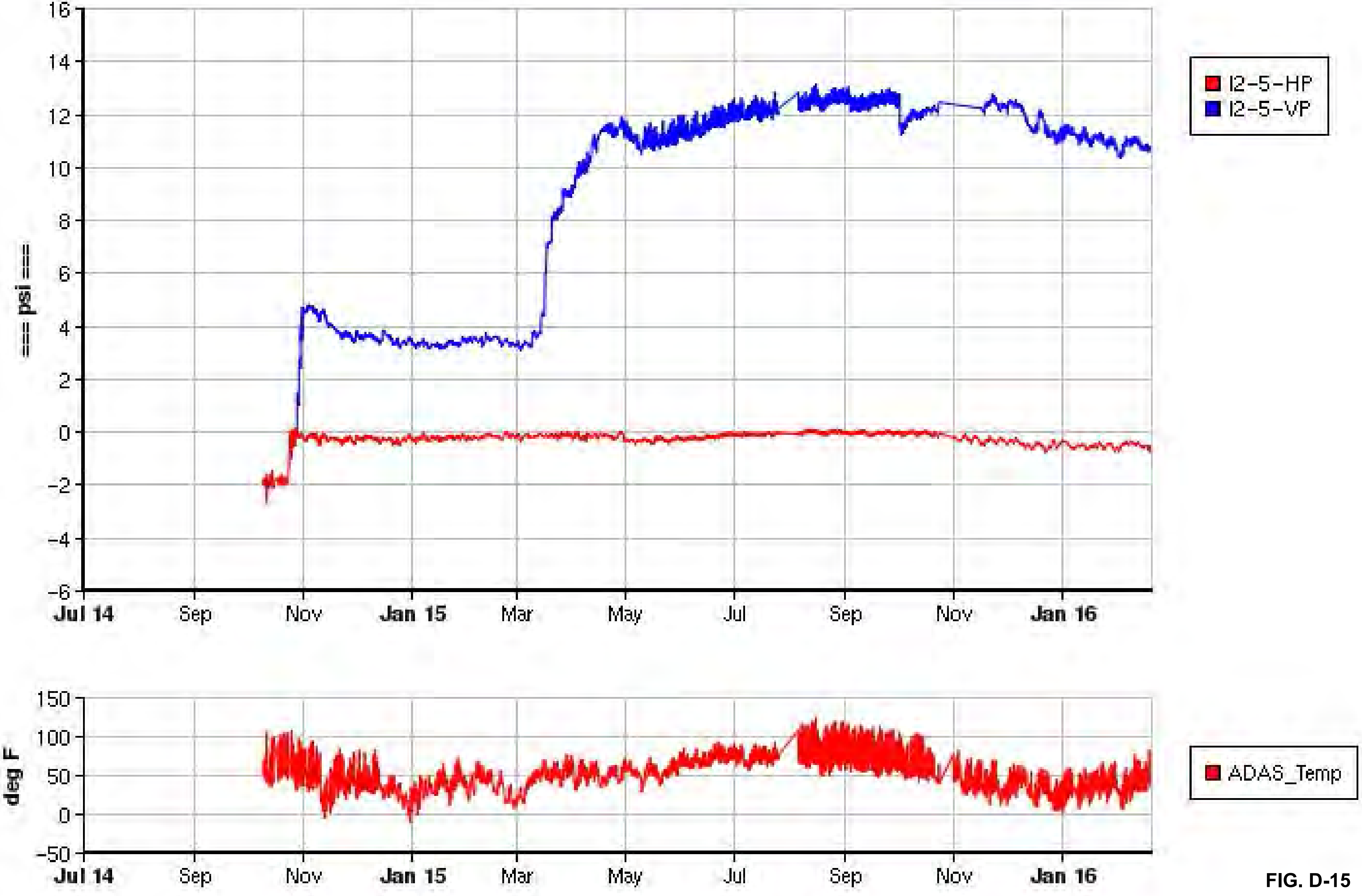

16
14
12
10
8
6
4
2
0
-2
-4
-6
=== psi ===
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
🟥 I2-5-HP
🟦 I2-5-VP
150
100
50
0
-50
deg F
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
🟥 ADAS_Temp

FIG. D-15

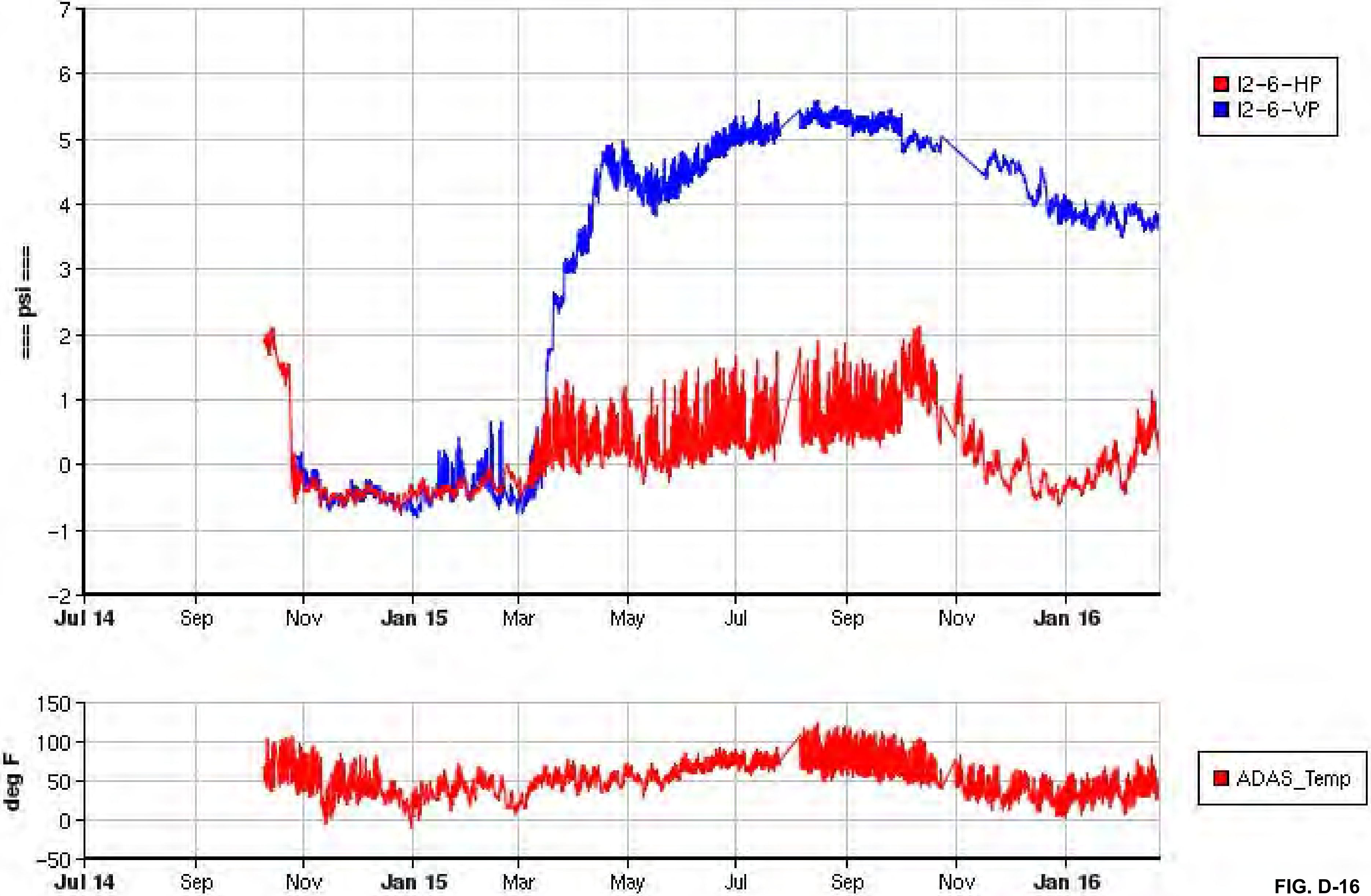
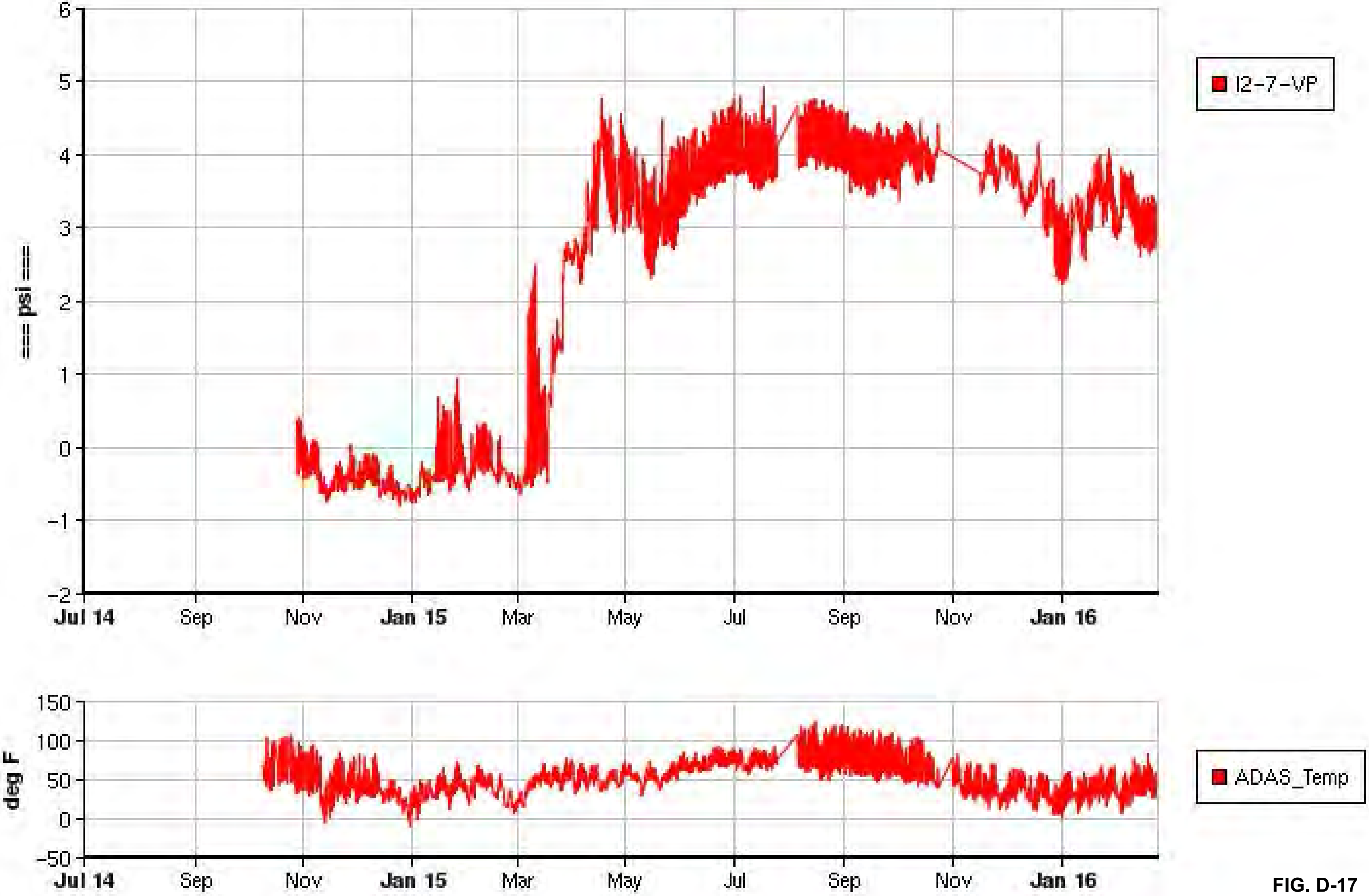
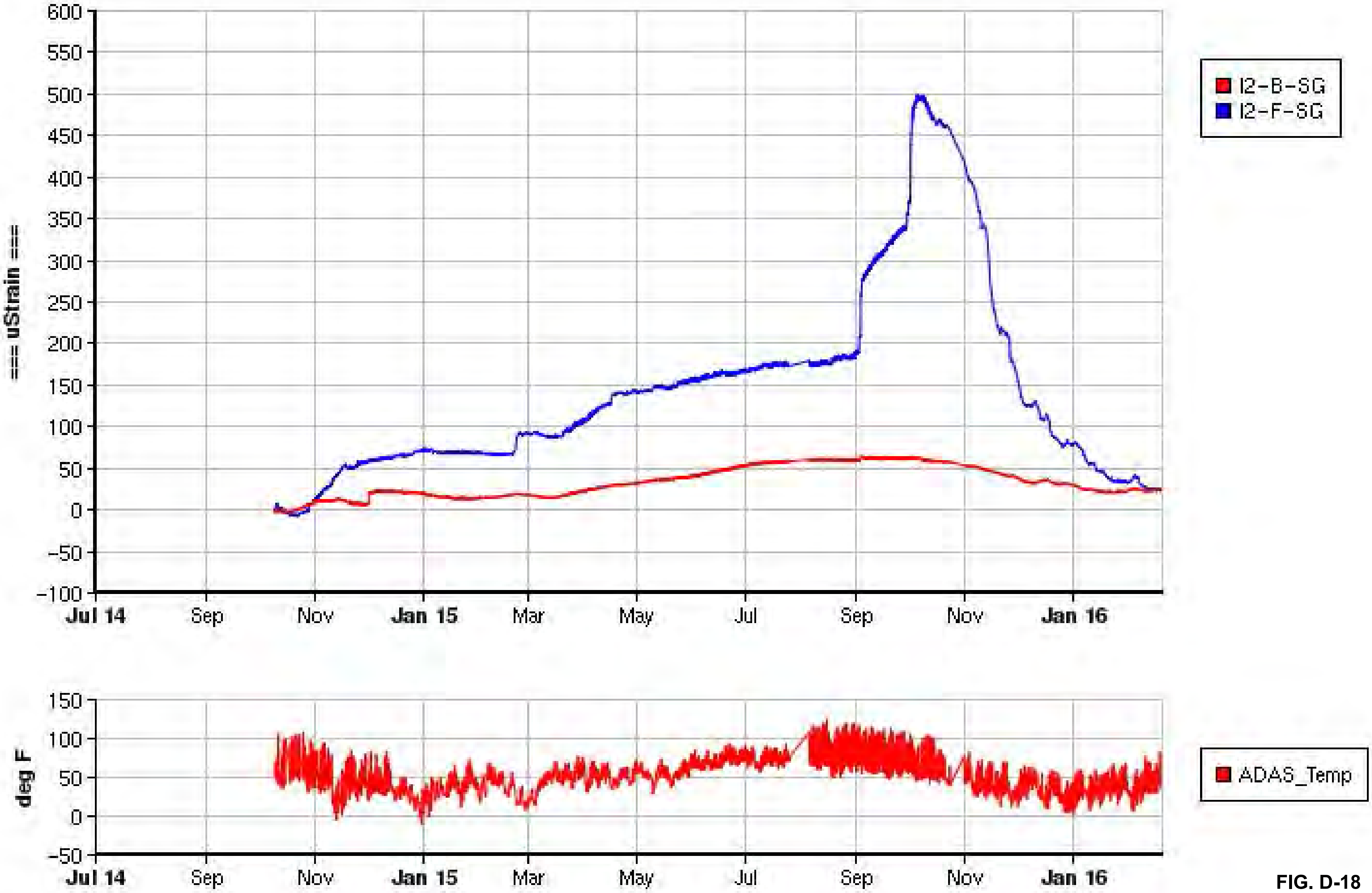

7
6
5
4
3
2
1
0
−1
−2
=== psi ===
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
🟥 I2-6-HP
🟦 I2-6-VP
150
100
50
0
−50
deg F
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
🟥 ADAS_Temp

FIG. D-16



=== psi ===
6
5
4
3
2
1
0
−1
−2
I2−7−VP
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
deg F
150
100
50
0
−50
ADAS_Temp
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16

FIG. D-17



=== uStrain ===
600
550
500
450
400
350
300
250
200
150
100
50
0
−50
−100
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
🟥 I2-B-SG
🟦 I2-F-SG
deg F
150
100
50
0
−50
Jul 14
Sep
Nov
Jan 15
Mar
May
Jul
Sep
Nov
Jan 16
🟥 ADAS_Temp

FIG. D-18

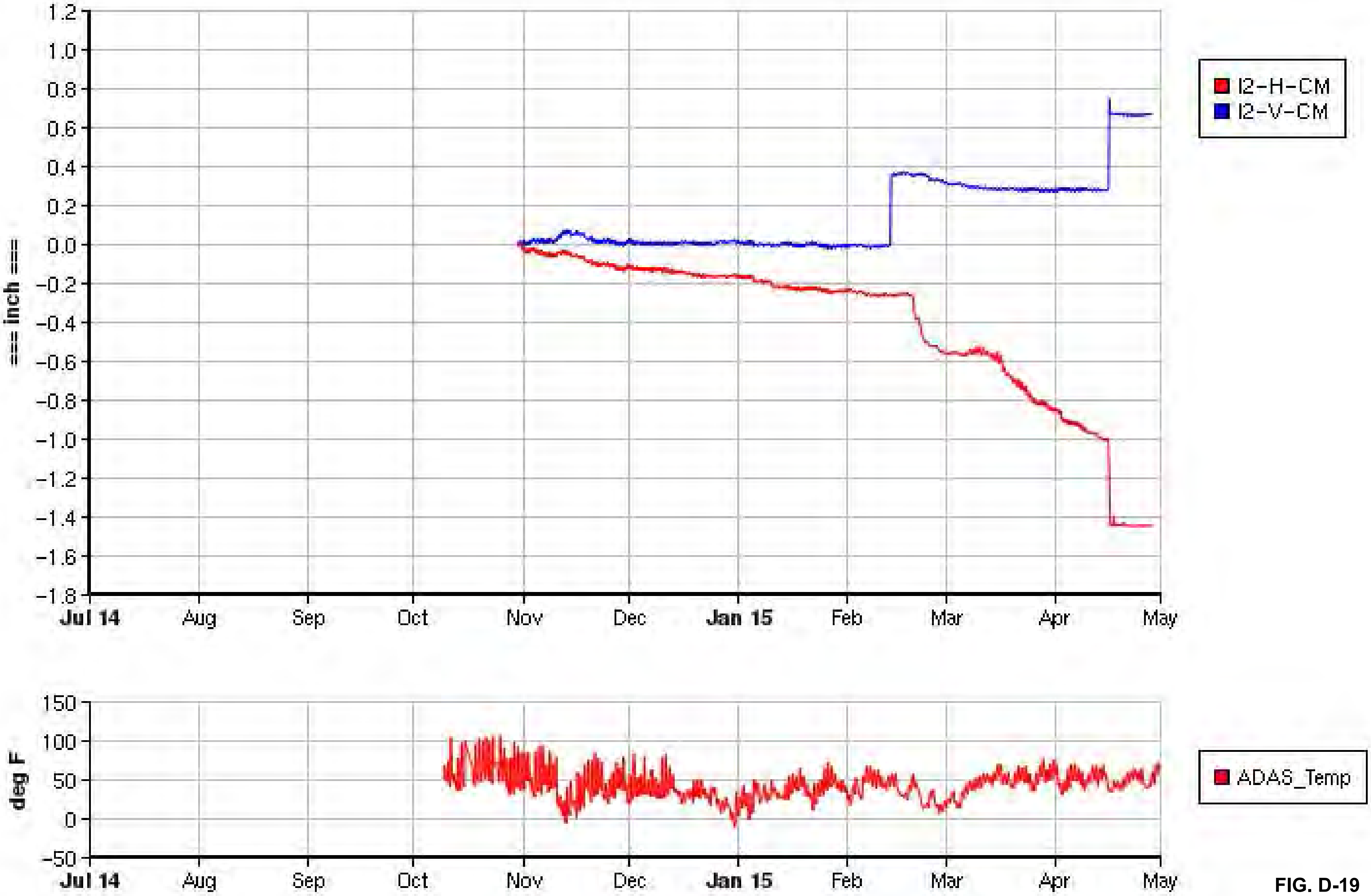

1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
−1.4
−1.6
−1.8
=== inch ===
Jul 14
Aug
Sep
Oct
Nov
Dec
Jan 15
Feb
Mar
Apr
May
🟥 I2−H−CM
🟦 I2−V−CM
150
100
50
0
−50
deg F
Jul 14
Aug
Sep
Oct
Nov
Dec
Jan 15
Feb
Mar
Apr
May
🟥 ADAS_Temp

FIG. D-19

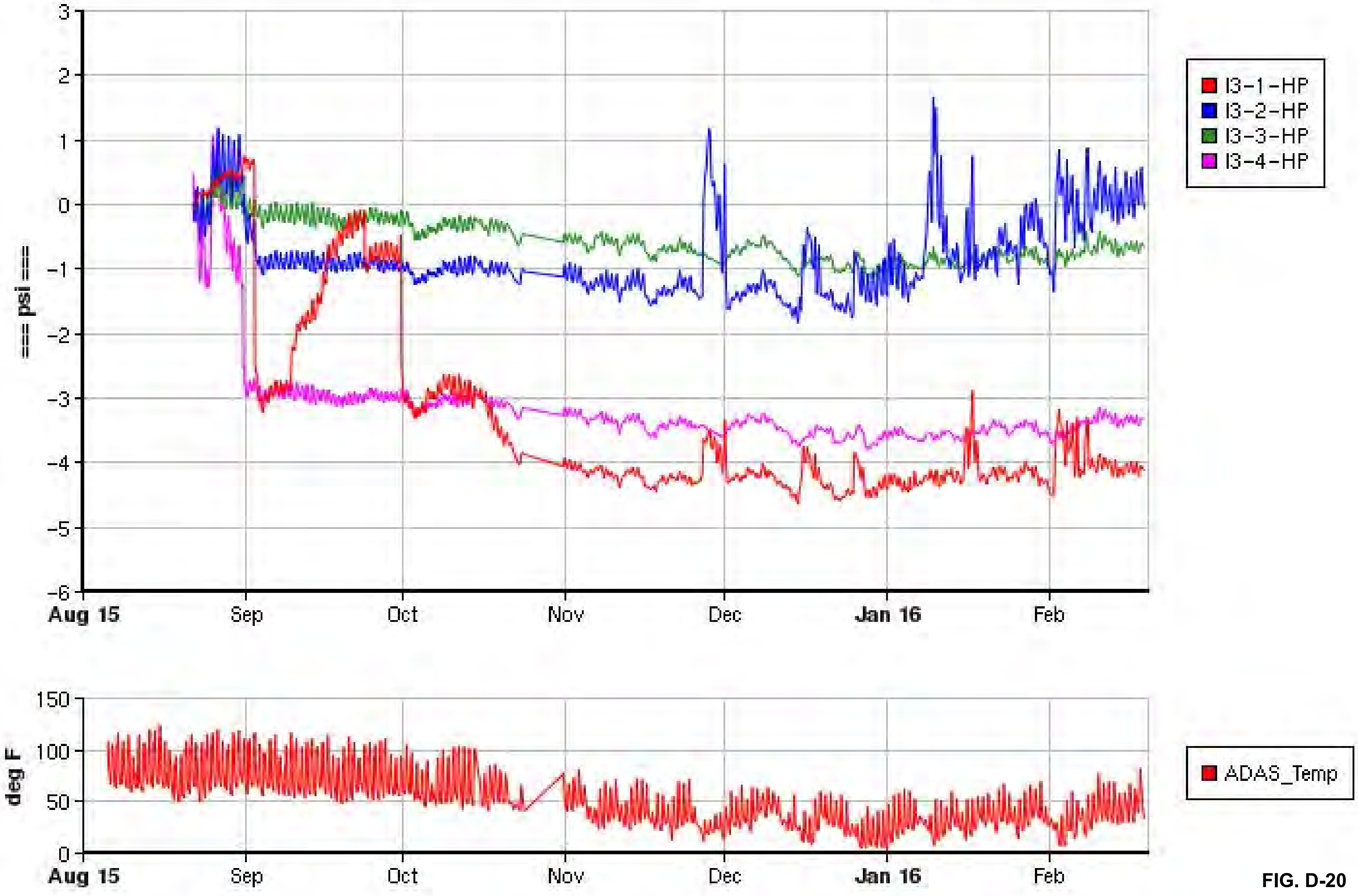

3
2
1
0
-1
-2
-3
-4
-5
-6
=== psi ===
Aug 15
Sep
Oct
Nov
Dec
Jan 16
Feb
I3-1-HP
I3-2-HP
I3-3-HP
I3-4-HP
150
100
50
0
deg F
Aug 15
Sep
Oct
Nov
Dec
Jan 16
Feb
ADAS_Temp

FIG. D-20

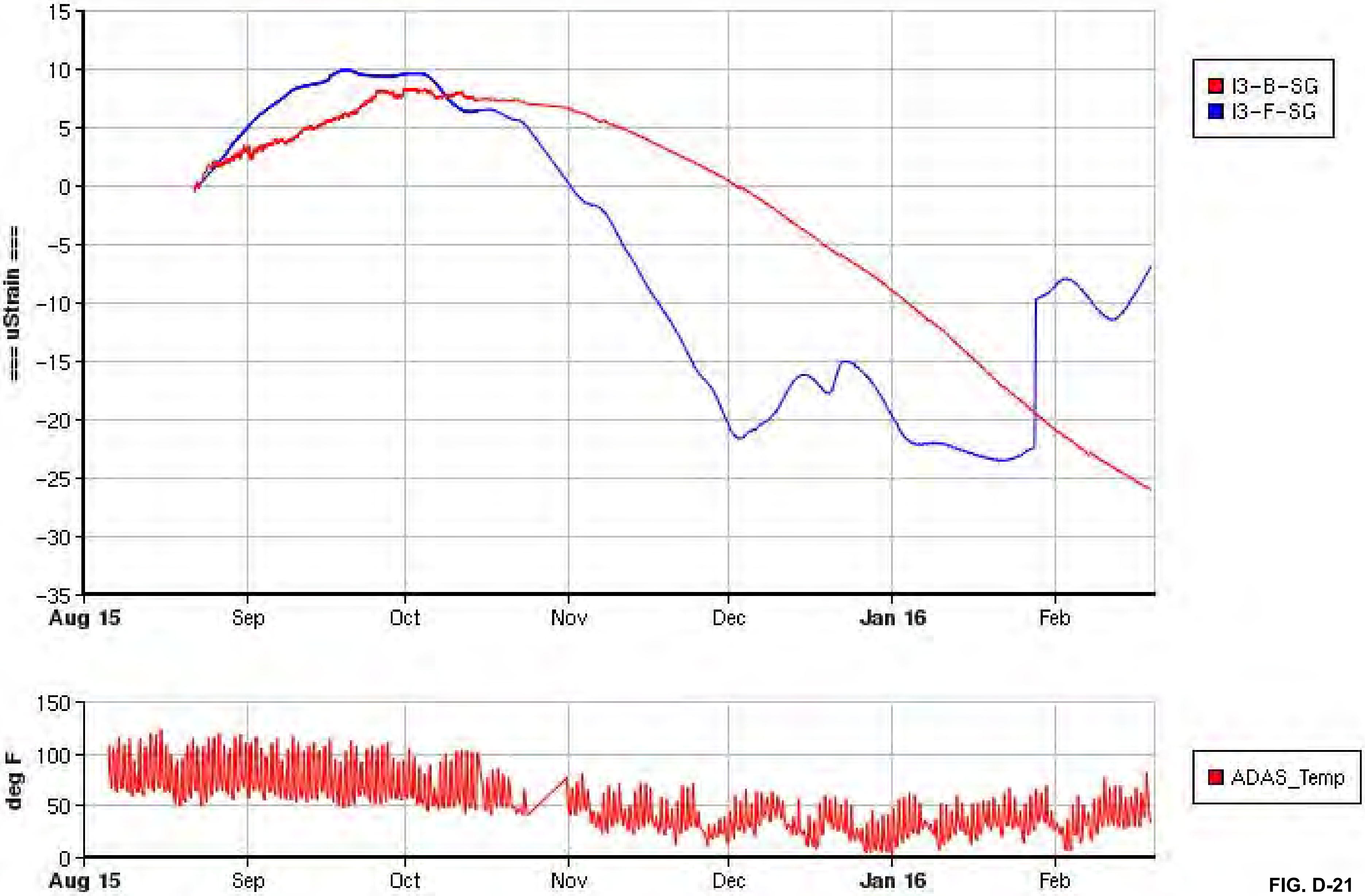

15
10
5
0
-5
-10
-15
-20
-25
-30
-35
=== uStrain ===
Aug 15
Sep
Oct
Nov
Dec
Jan 16
Feb
🟥 I3-B-SG
🟦 I3-F-SG
150
100
50
0
deg F
Aug 15
Sep
Oct
Nov
Dec
Jan 16
Feb
🟥 ADAS_Temp

FIG. D-21

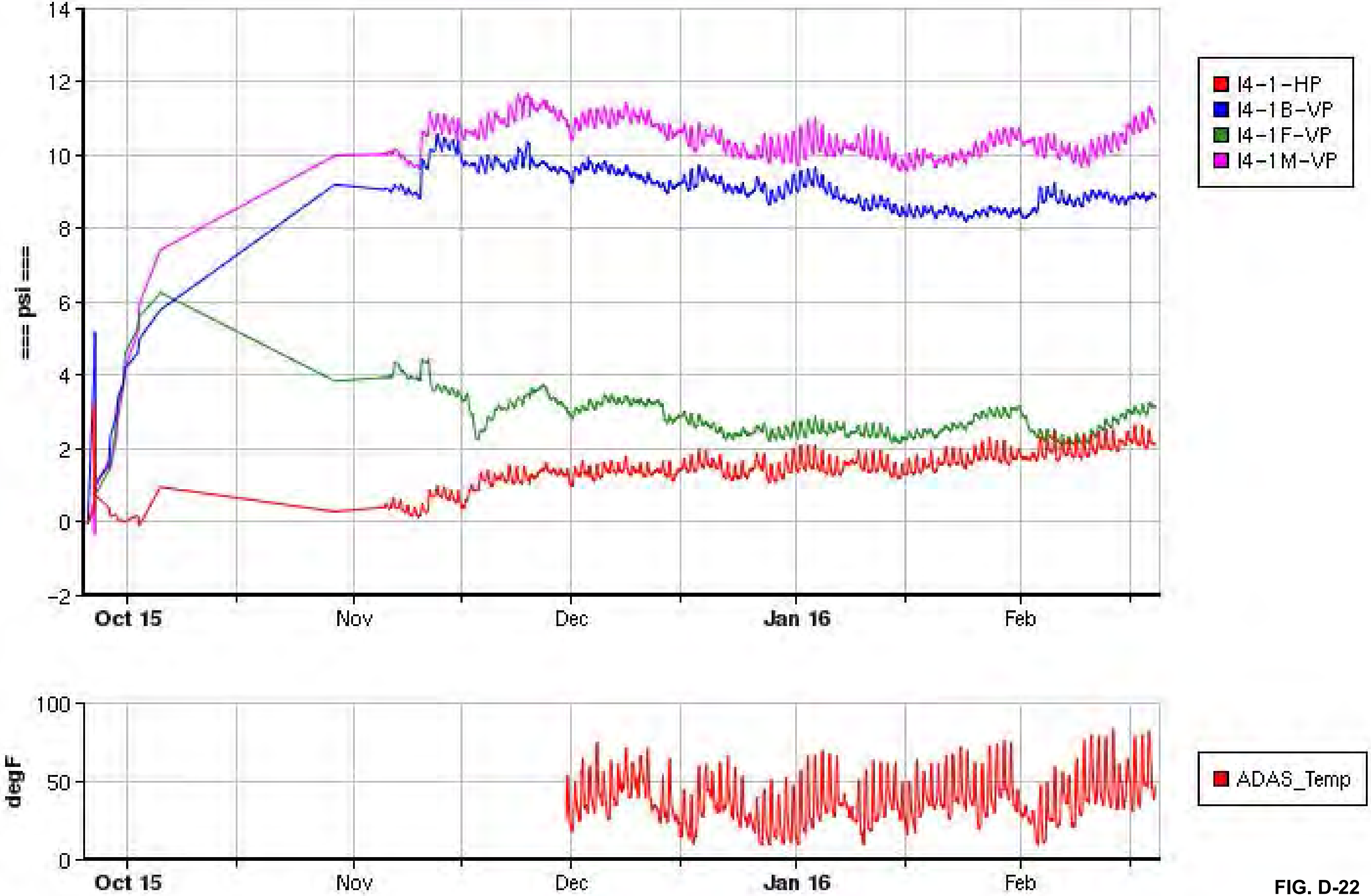

14
12
10
8
6
4
2
0
-2
=== psi ===
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I4-1-HP
🟦 I4-1B-VP
🟩 I4-1F-VP
🟪 I4-1M-VP
100
50
0
degF
Oct 15
Nov
Dec
Jan 16
Feb
🟥 ADAS_Temp

FIG. D-22

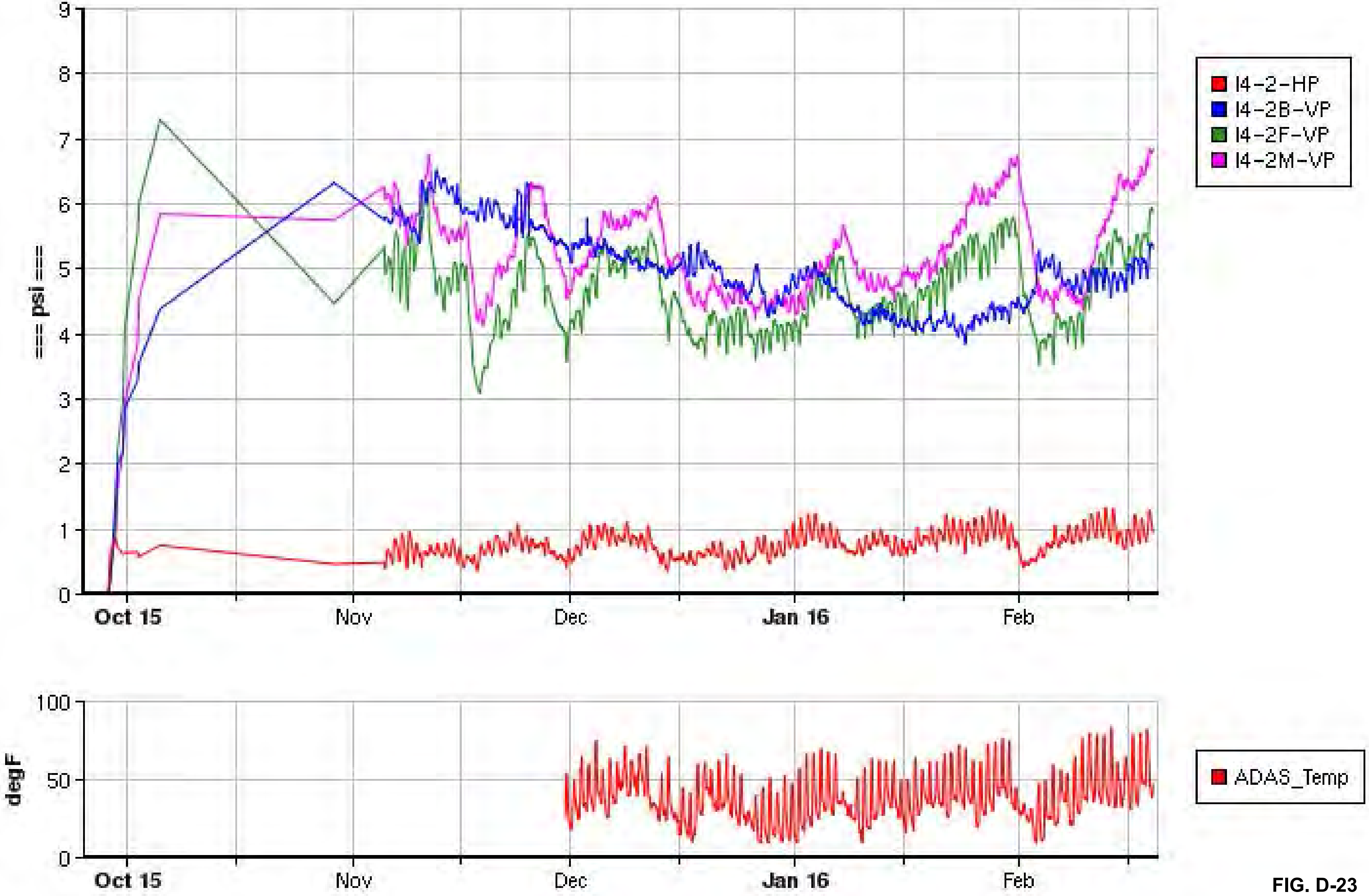
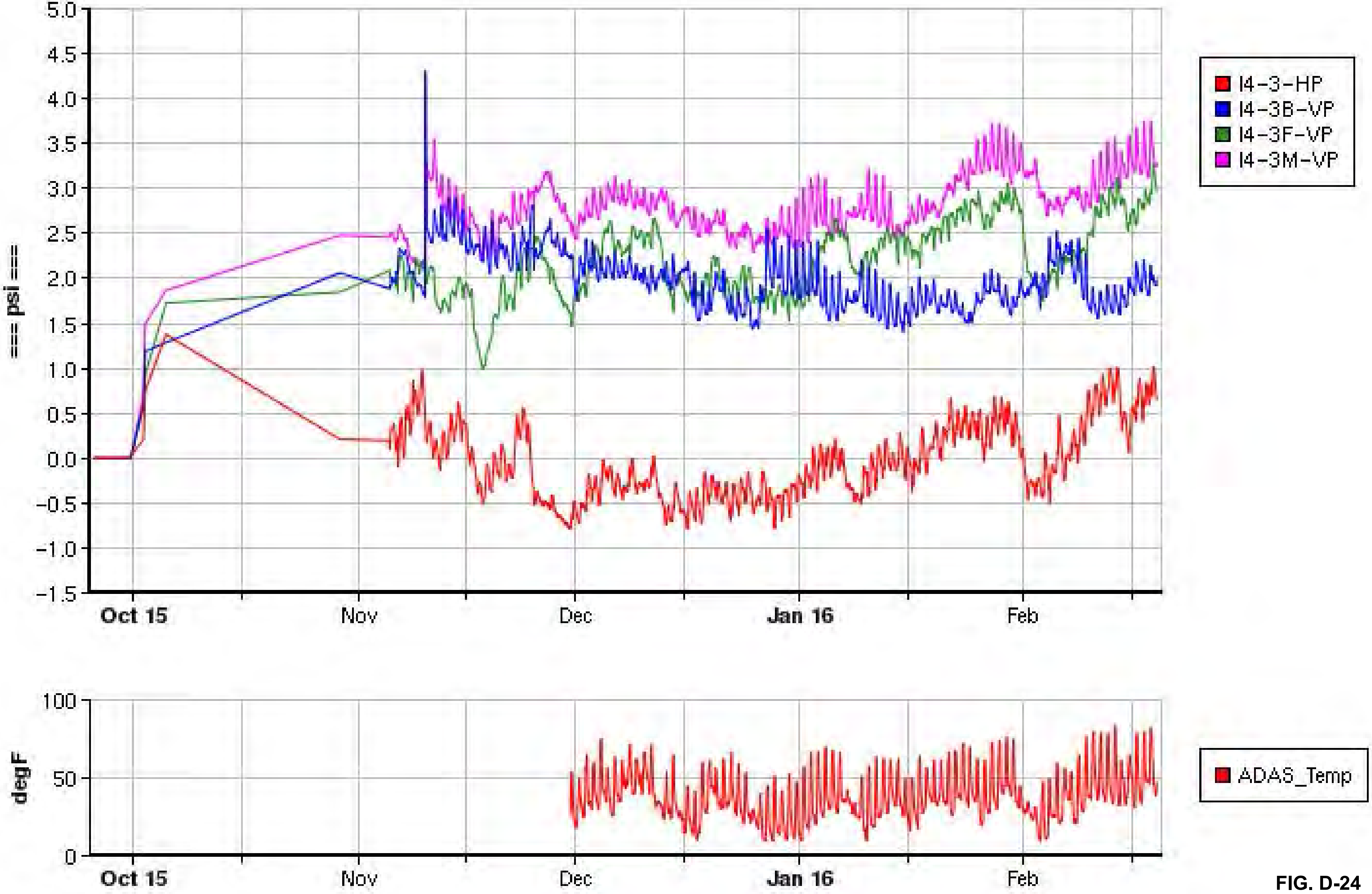

9
8
7
6
5
4
3
2
1
0
=== psi ===
Oct 15
Nov
Dec
Jan 16
Feb
I4-2-HP
I4-2B-VP
I4-2F-VP
I4-2M-VP
100
50
0
degF
Oct 15
Nov
Dec
Jan 16
Feb
ADAS_Temp

FIG. D-23



=== psi ===
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I4-3-HP
🟦 I4-3B-VP
🟩 I4-3F-VP
🟪 I4-3M-VP
degF
100
50
0
Oct 15
Nov
Dec
Jan 16
Feb
🟥 ADAS_Temp

FIG. D-24

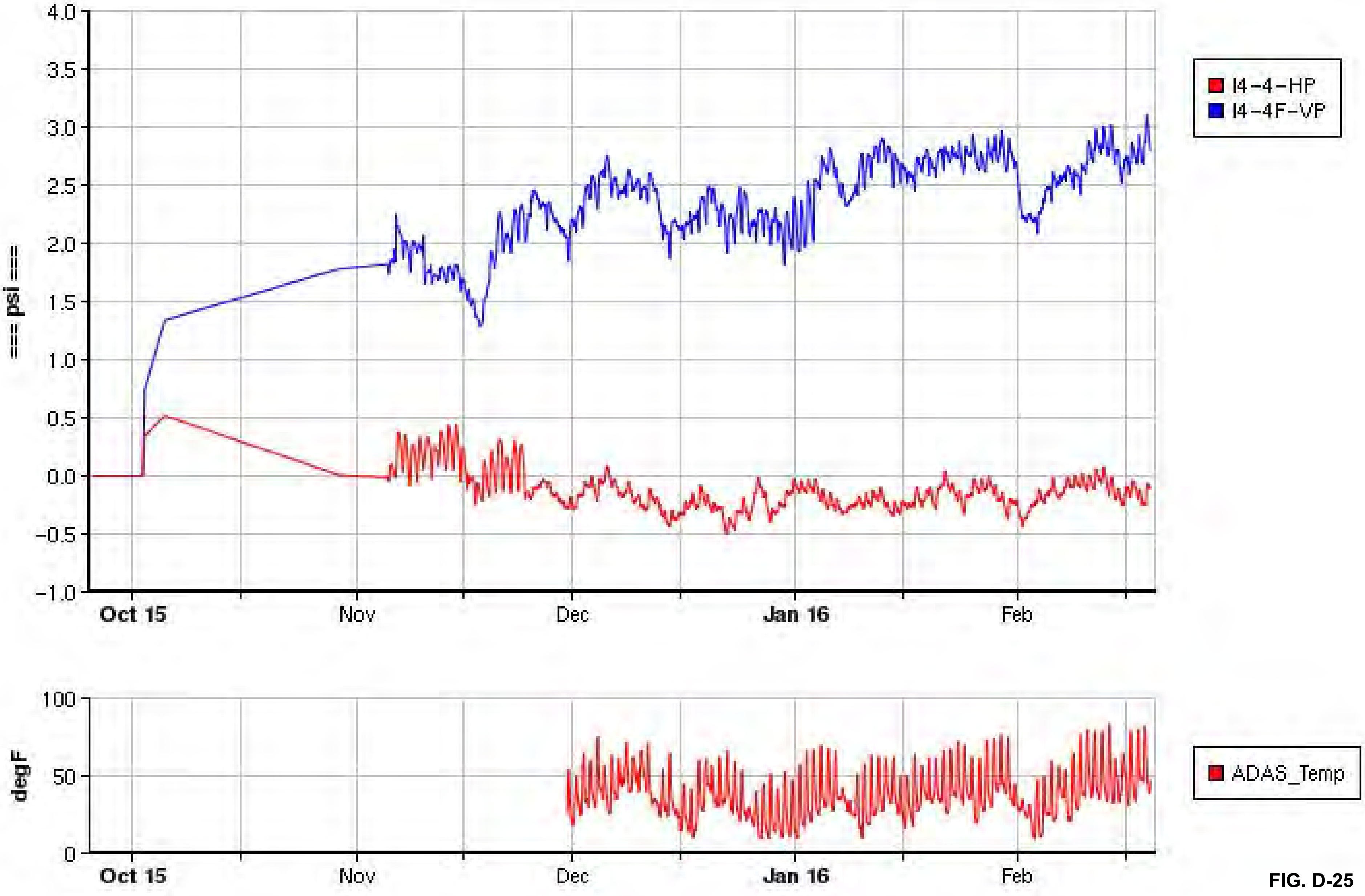

4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
=== psi ===
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I4-4-HP
🟦 I4-4F-VP
100
50
0
degF
Oct 15
Nov
Dec
Jan 16
Feb
🟥 ADAS_Temp

FIG. D-25

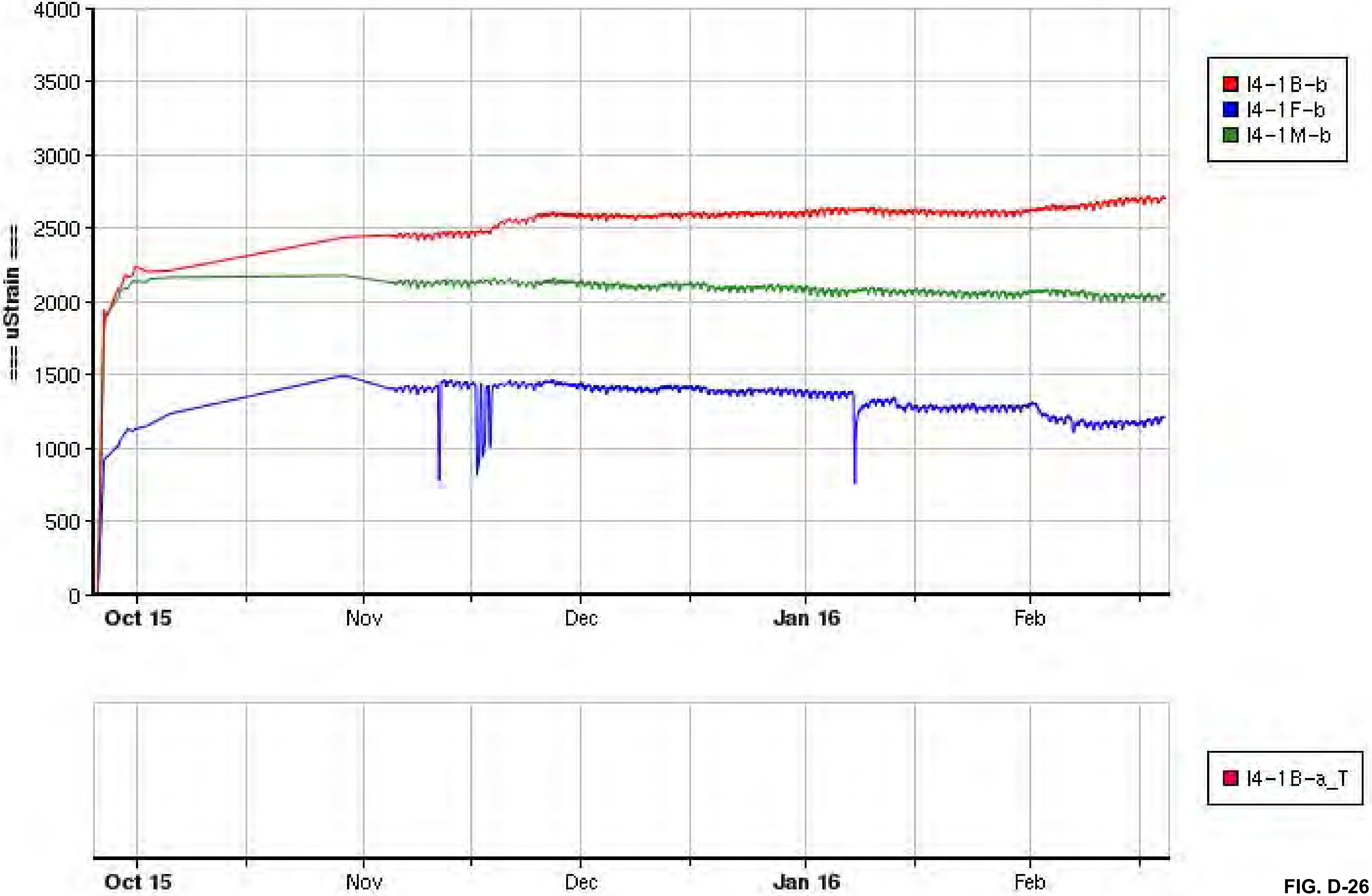

4000
3500
3000
2500
2000
1500
1000
500
0
=== uStrain ===
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I4−1B−b
🟦 I4−1F−b
🟩 I4−1M−b
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I4−1B−a_T

FIG. D-26

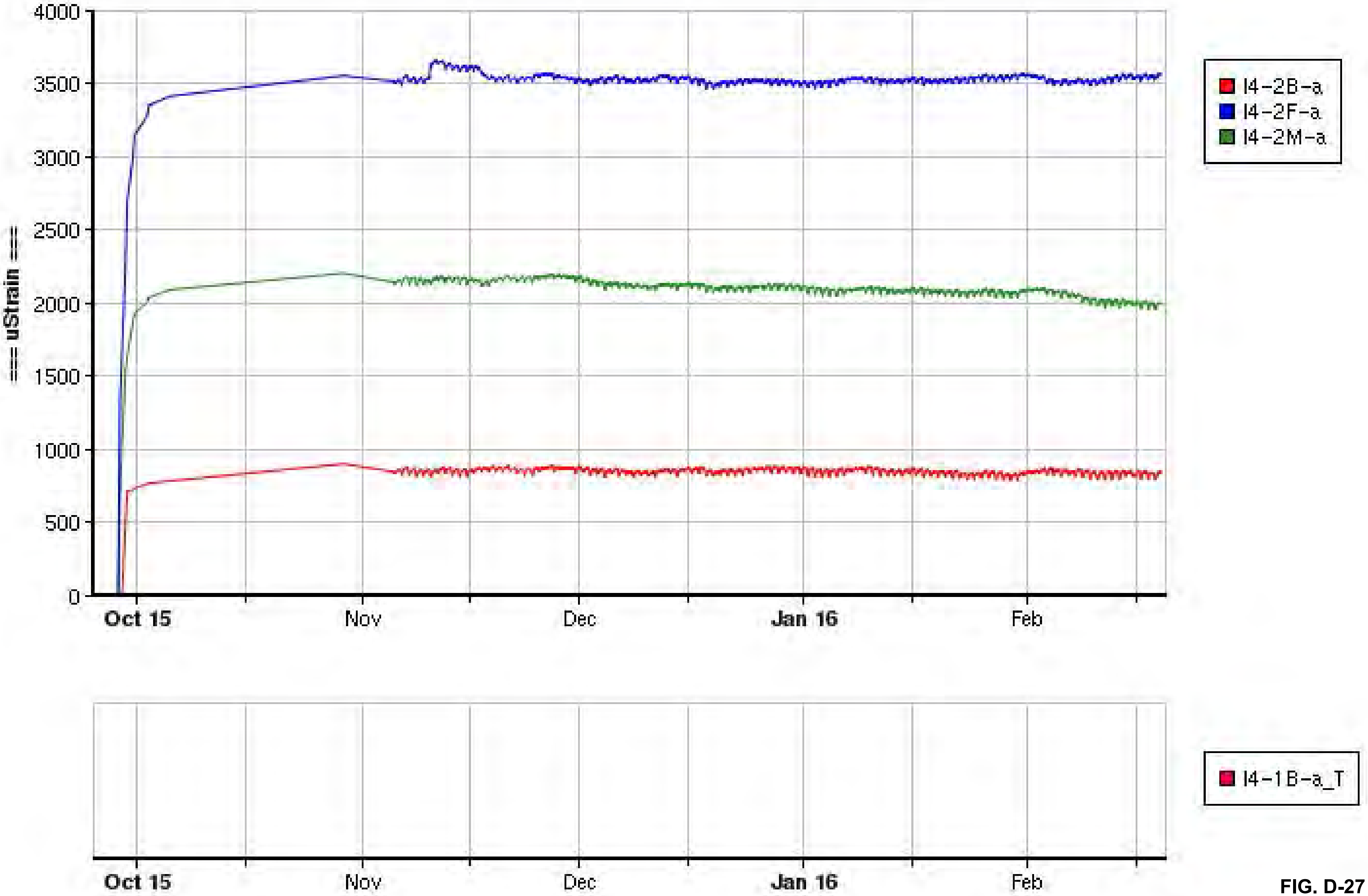

4000
3500
3000
2500
2000
1500
1000
500
0
== uStrain ==
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I4-2B-a
🟦 I4-2F-a
🟩 I4-2M-a
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I4-1B-a_T

FIG. D-27

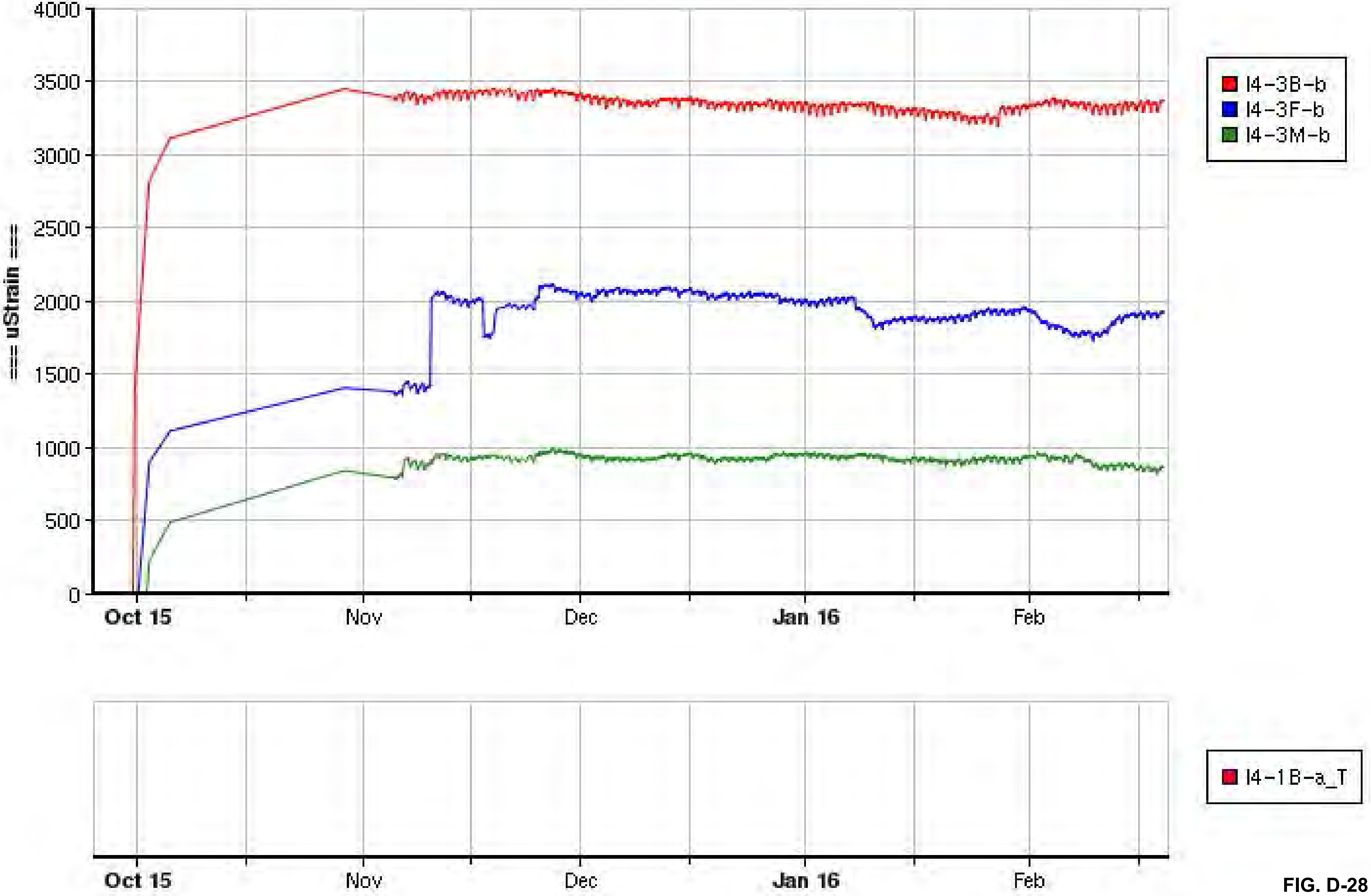

4000
3500
3000
2500
2000
1500
1000
500
0
=== uStrain ===
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I4-3B-b
🟦 I4-3F-b
🟩 I4-3M-b
🟥 I4-1B-a_T
Oct 15
Nov
Dec
Jan 16
Feb

FIG. D-28

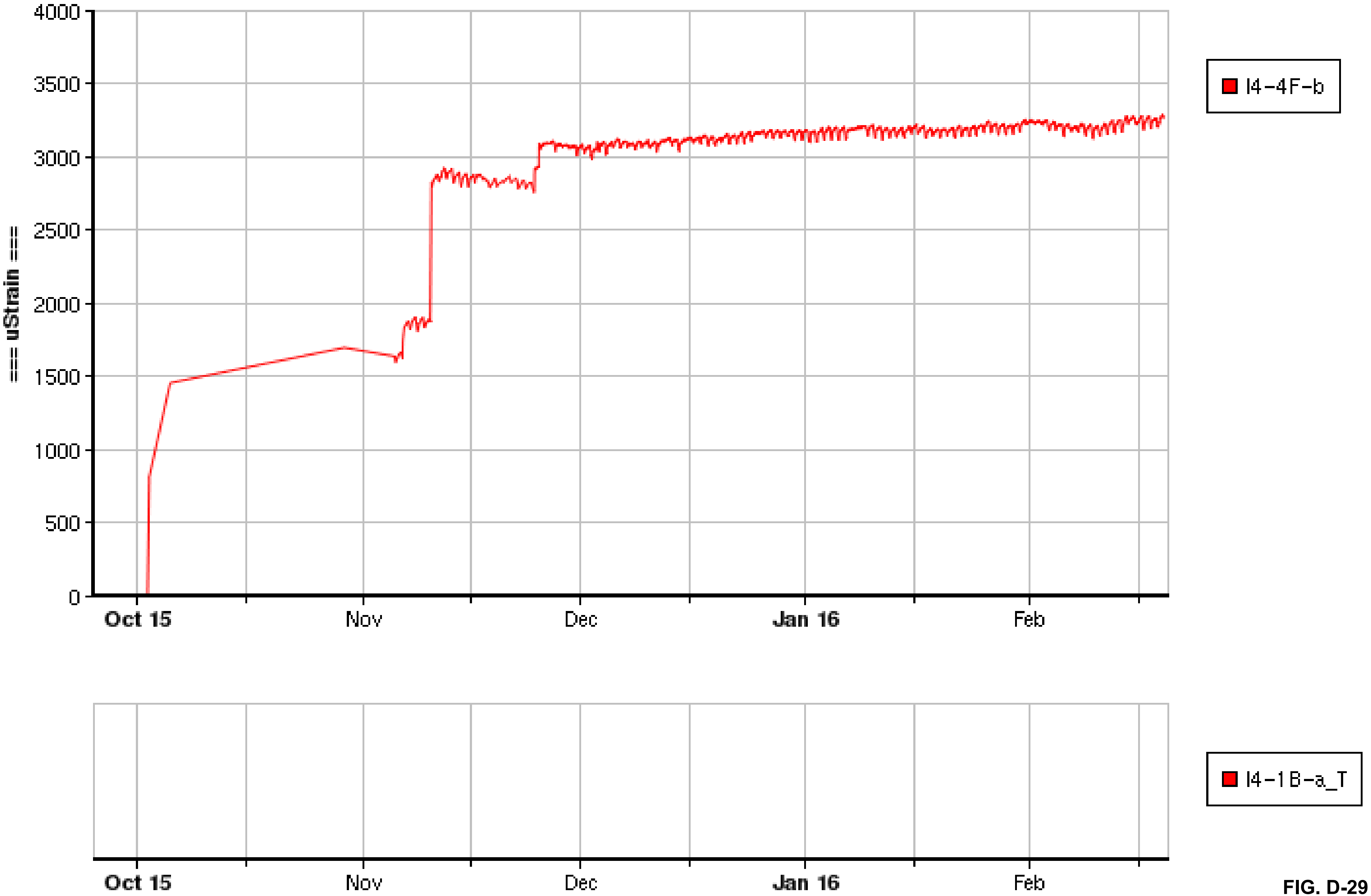

4000
3500
3000
2500
2000
1500
1000
500
0
=== uStrain ===
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I4-4F-b
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I4-1B-a_T

FIG. D-29

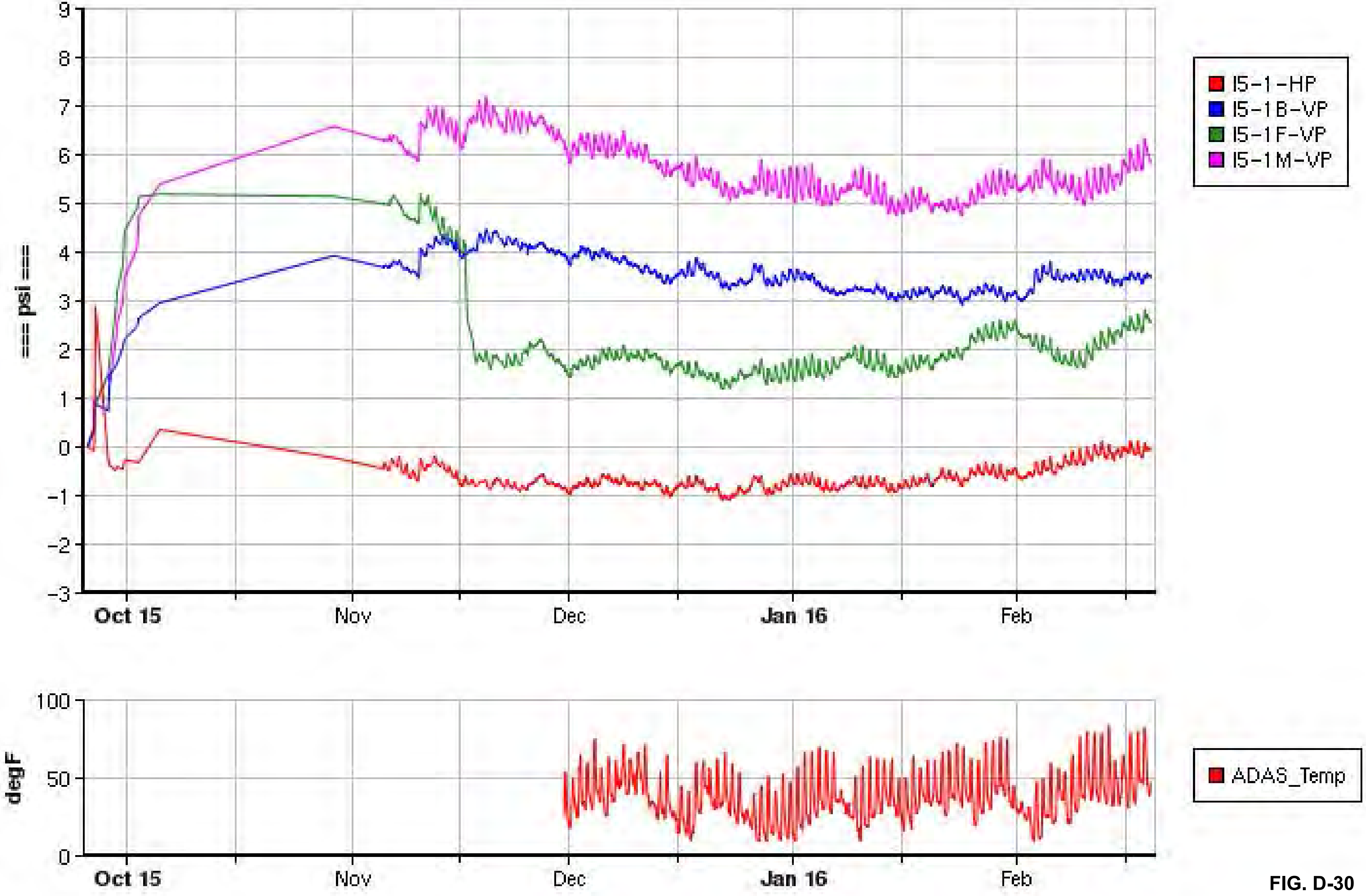

9
8
7
6
5
4
3
2
1
0
−1
−2
−3
=== psi ===
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I5−1−HP
🟦 I5−1B−VP
🟩 I5−1F−VP
🟪 I5−1M−VP
100
50
0
degF
Oct 15
Nov
Dec
Jan 16
Feb
🟥 ADAS_Temp

FIG. D-30

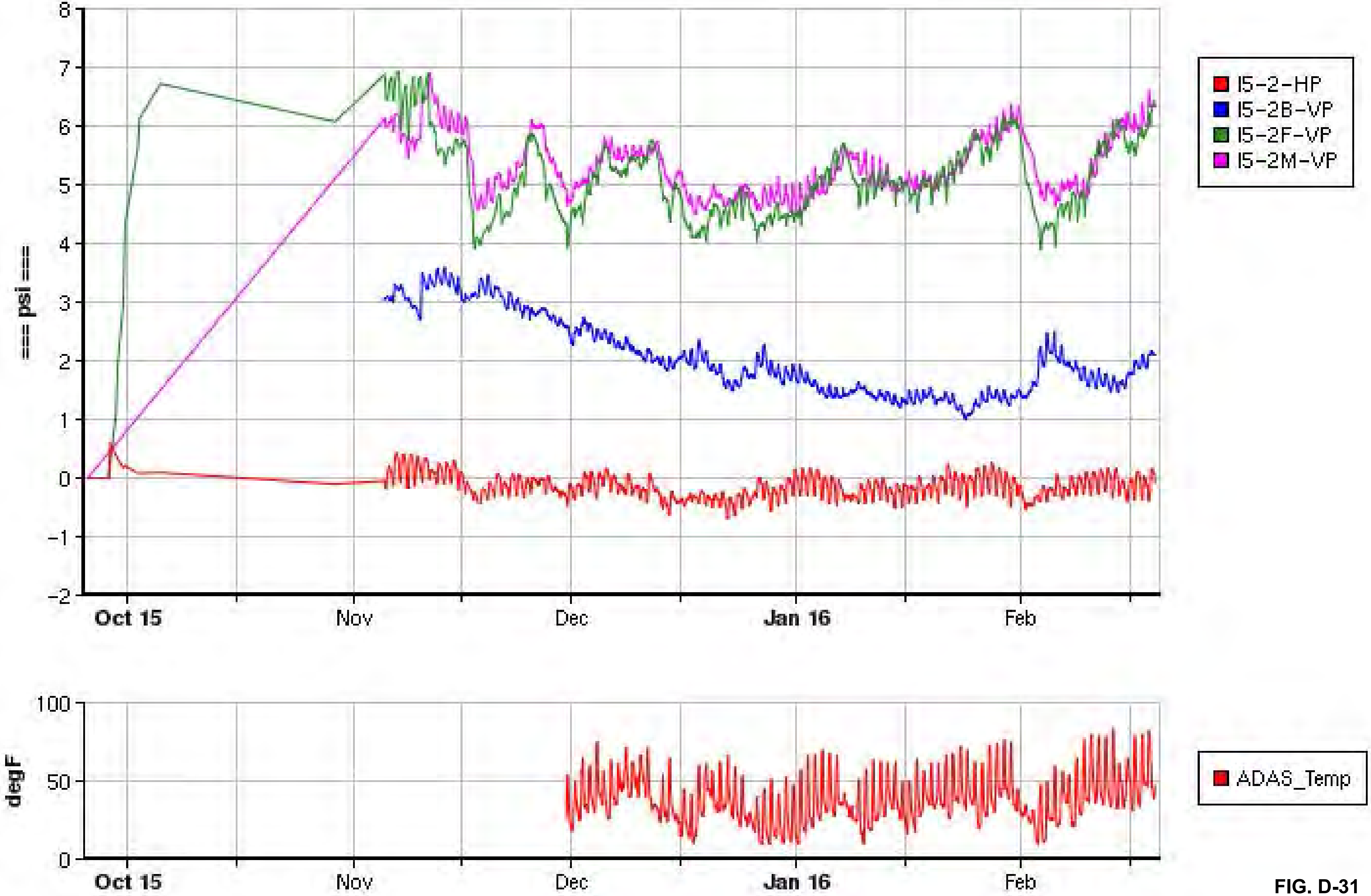

=== psi ===
8
7
6
5
4
3
2
1
0
−1
−2
Oct 15
Nov
Dec
Jan 16
Feb
I5−2−HP
I5−2B−VP
I5−2F−VP
I5−2M−VP
degF
100
50
0
Oct 15
Nov
Dec
Jan 16
Feb
ADAS_Temp

FIG. D-31

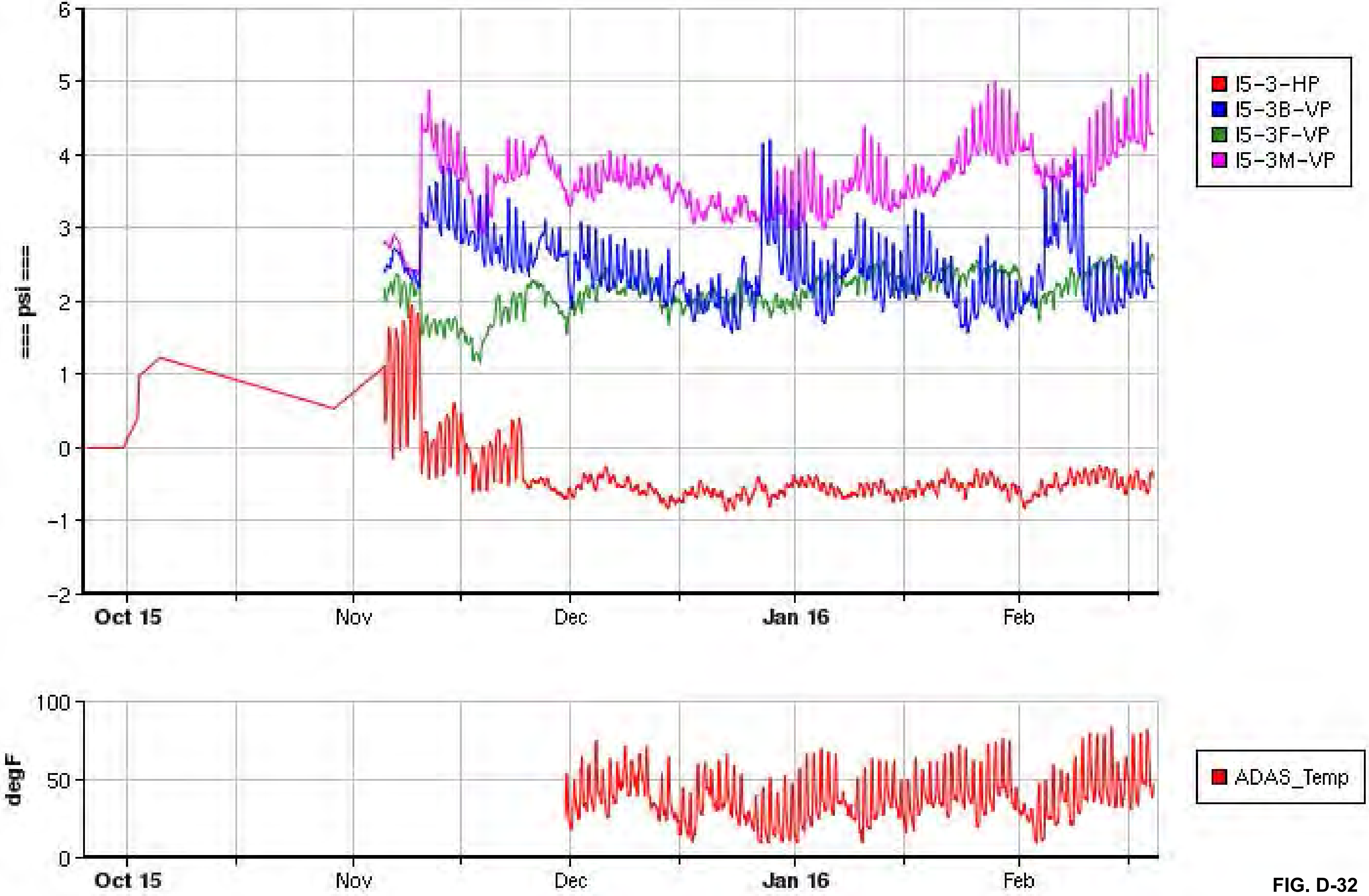

6
5
4
3
2
1
0
-1
-2
=== psi ===
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I5-3-HP
🟦 I5-3B-VP
🟩 I5-3F-VP
🟪 I5-3M-VP
100
50
0
degF
Oct 15
Nov
Dec
Jan 16
Feb
🟥 ADAS_Temp

FIG. D-32

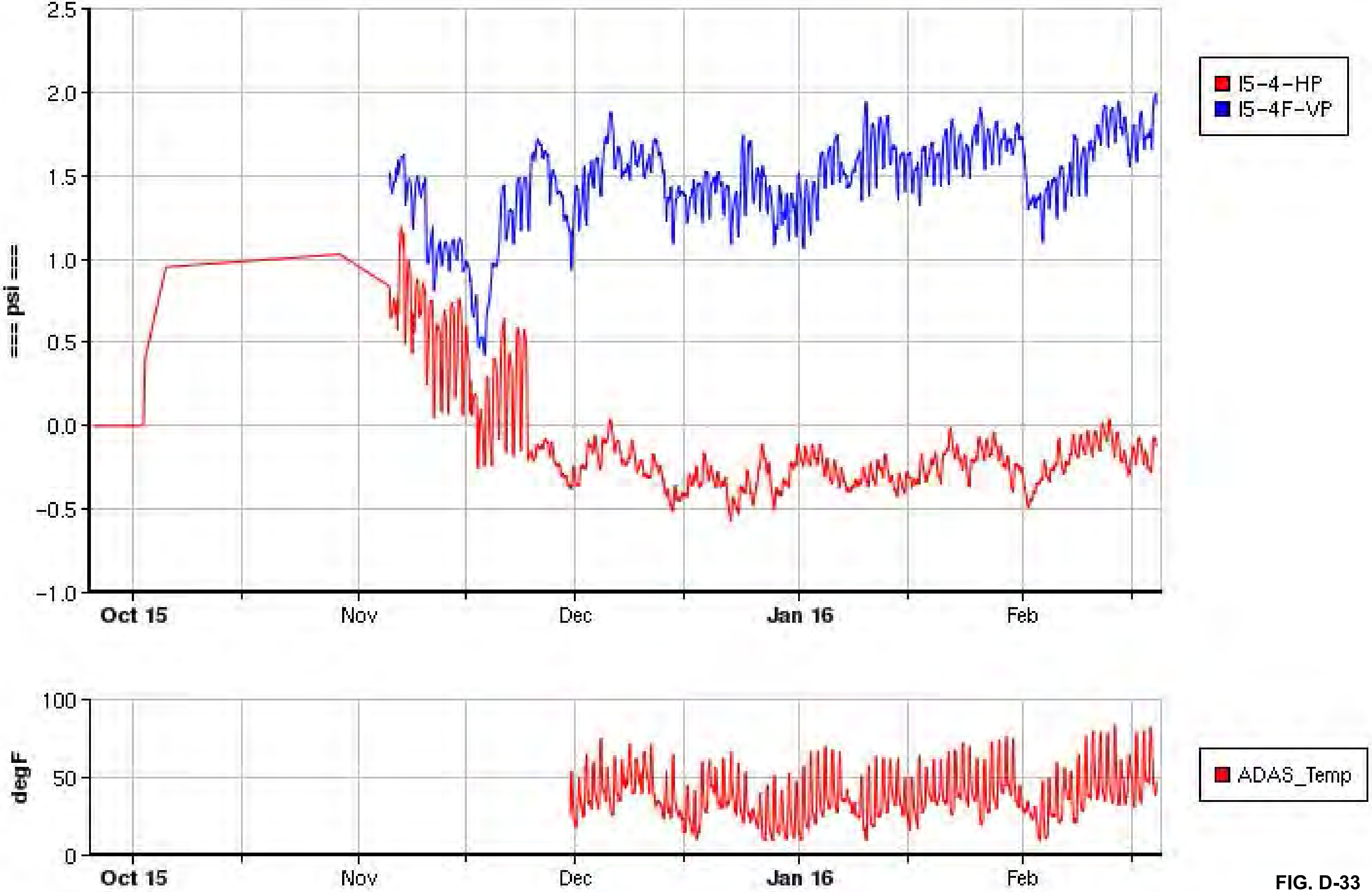

2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
=== psi ===
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I5-4-HP
🟦 I5-4F-VP
100
50
0
degF
Oct 15
Nov
Dec
Jan 16
Feb
🟥 ADAS_Temp

FIG. D-33

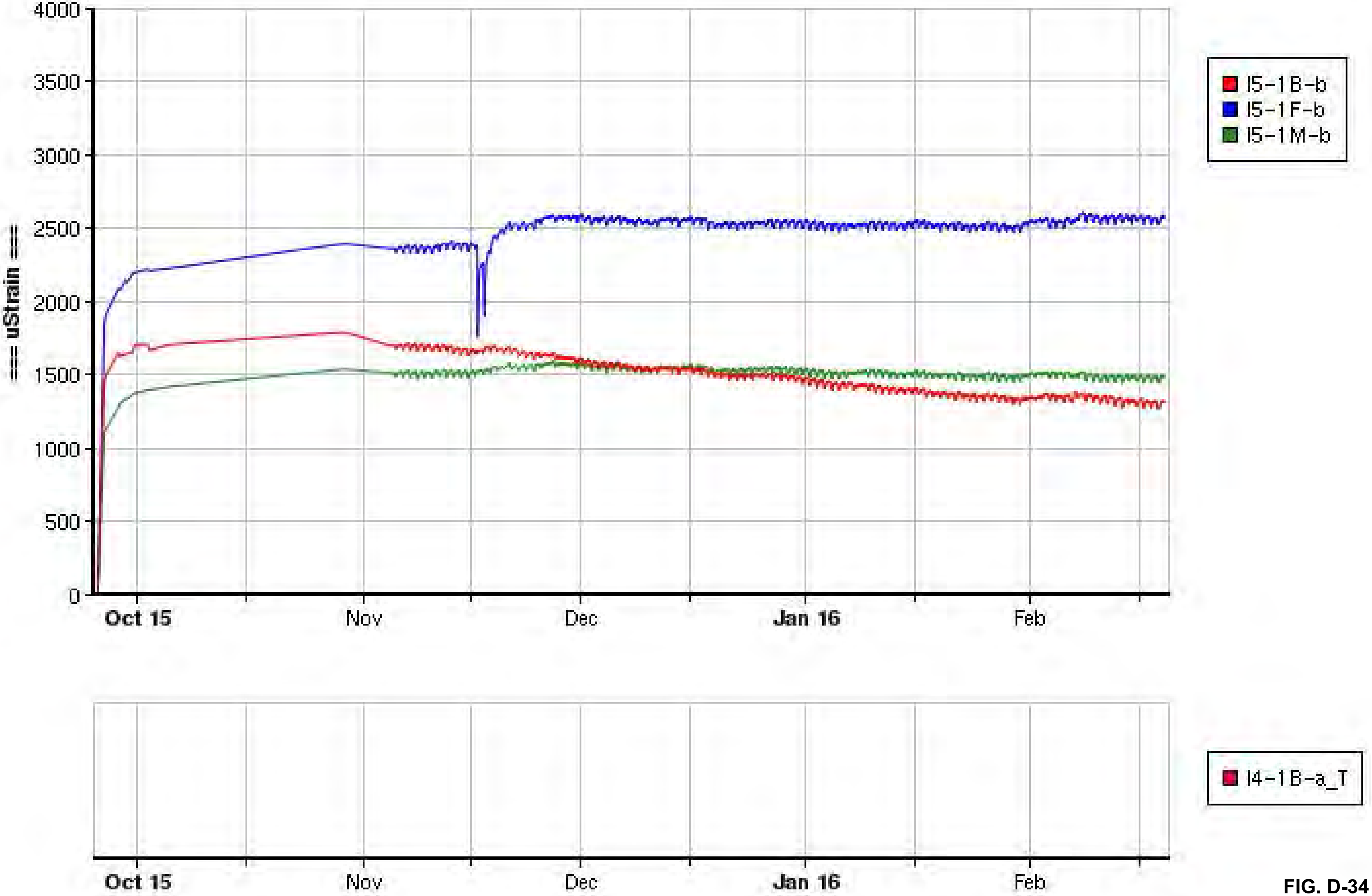

4000
3500
3000
2500
2000
1500
1000
500
0
== uStrain ==
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I5-1B-b
🟦 I5-1F-b
🟩 I5-1M-b
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I4-1B-a_T

FIG. D-34

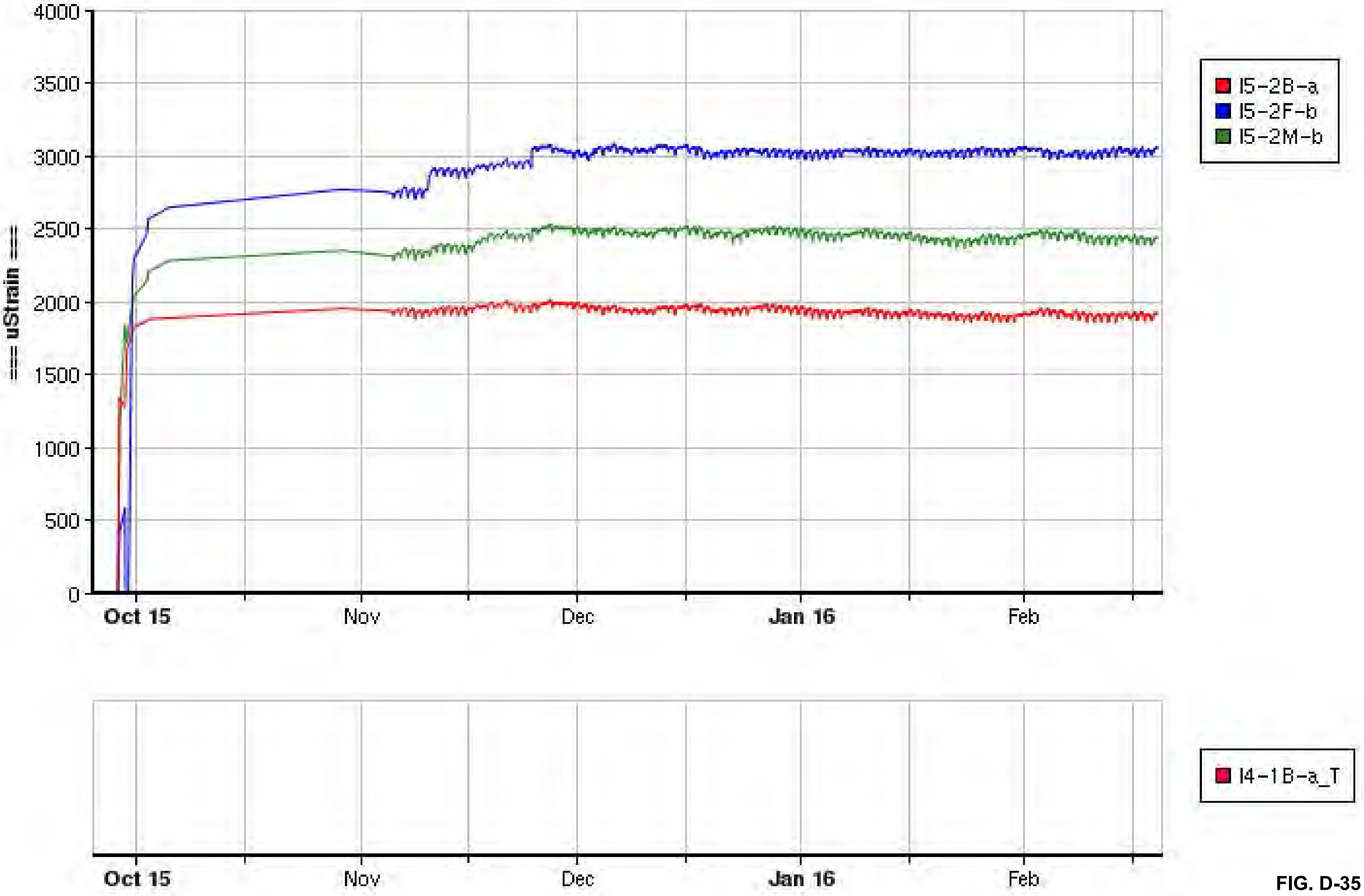

4000
3500
3000
2500
2000
1500
1000
500
0
== uStrain ==
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I5-2B-a
🟦 I5-2F-b
🟩 I5-2M-b
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I4-1B-a_T

FIG. D-35

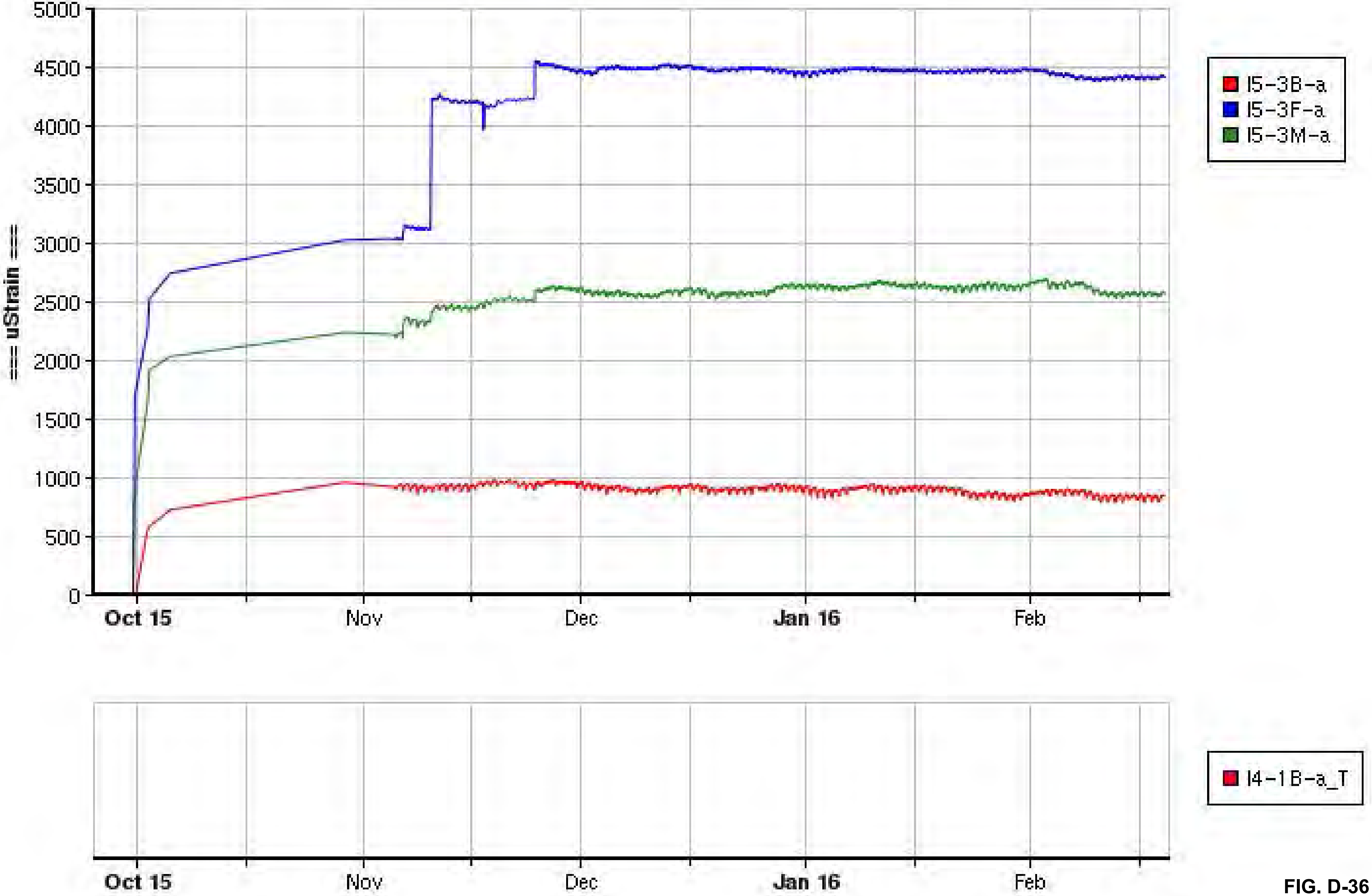

=== uStrain ===
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I5-3B-a
🟦 I5-3F-a
🟩 I5-3M-a
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I4-1B-a_T

FIG. D-36

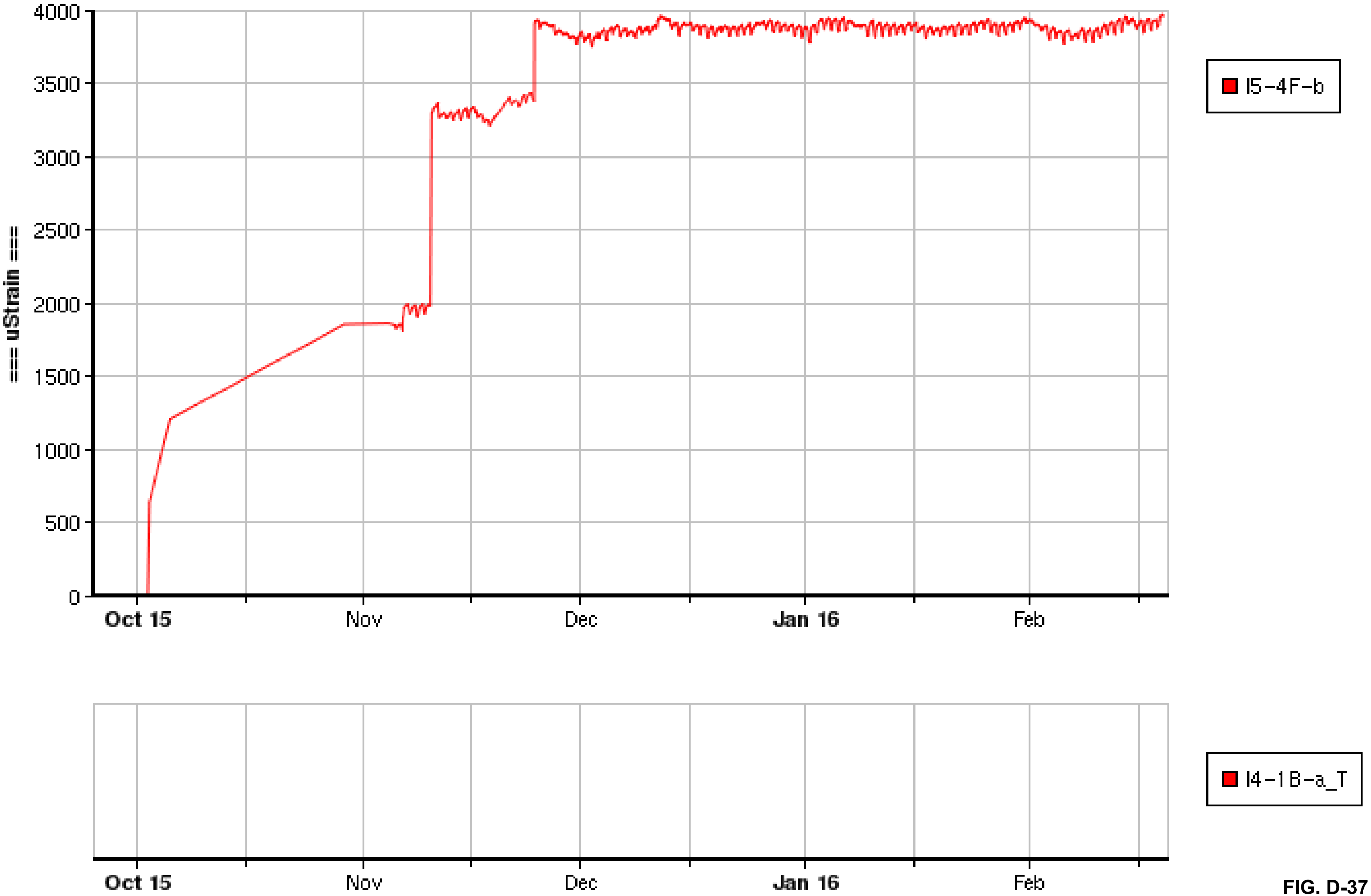

4000
3500
3000
2500
2000
1500
1000
500
0
=== uStrain ===
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I5-4F-b
Oct 15
Nov
Dec
Jan 16
Feb
🟥 I4-1B-a_T

FIG. D-37

FABRIC FIBER OPTIC
STRAIN INSTRUMENTATION - LINE 1
1ST LEVEL - FABRIC # 13001

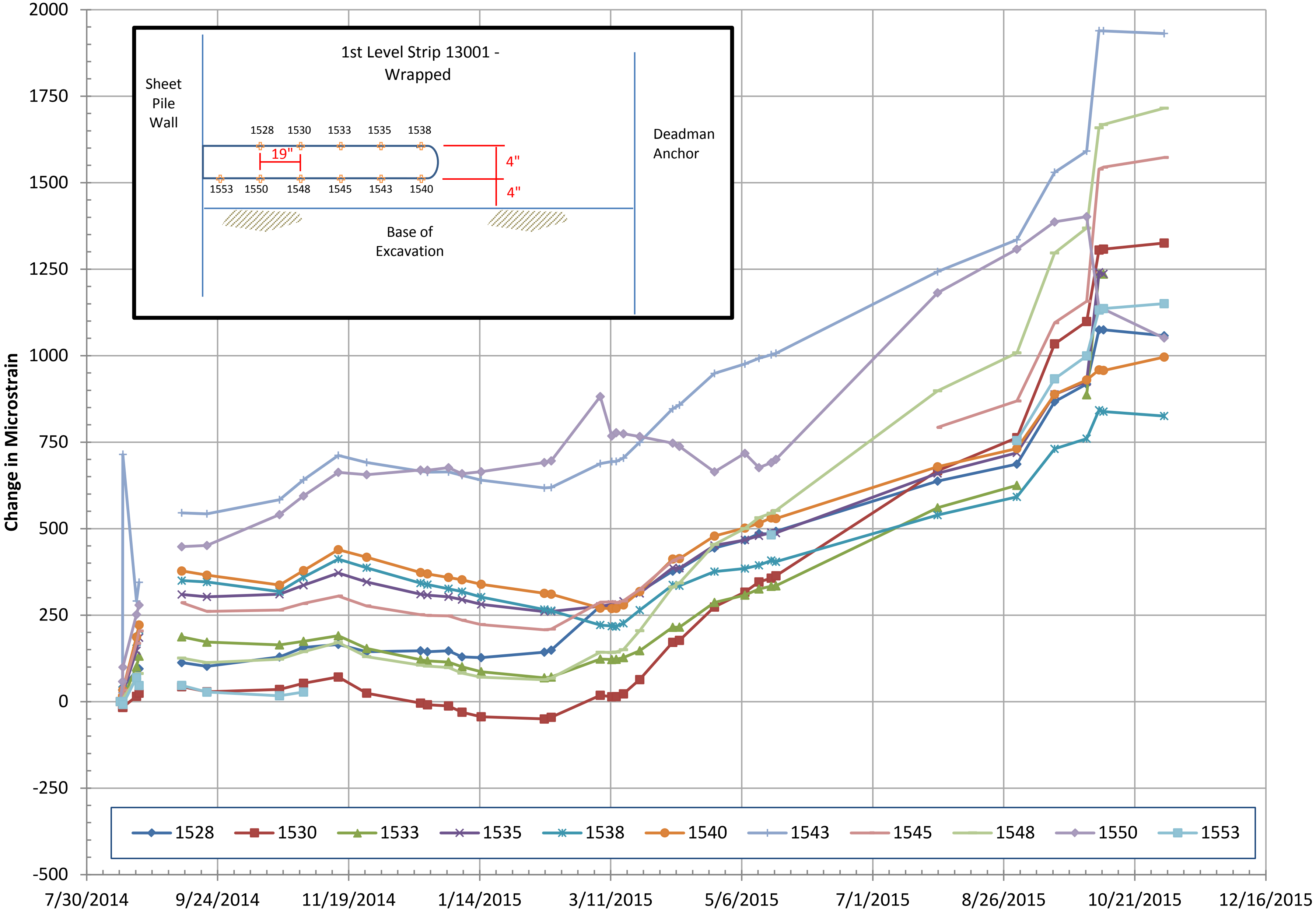


FIG. D-38

FABRIC FIBER OPTIC
STRAIN INSTRUMENTATION - LINE 1
2ND LEVEL - FABRIC # 13002R

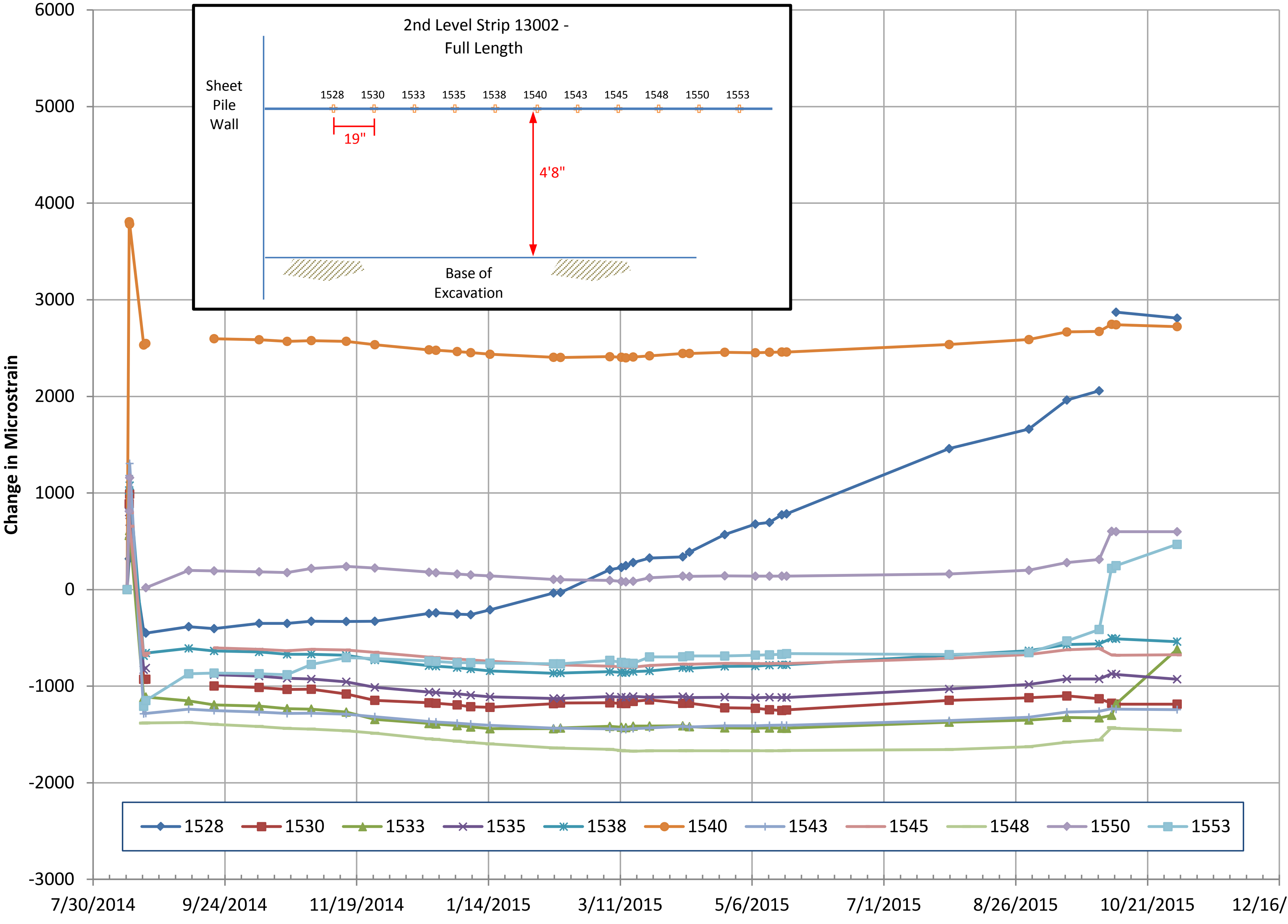


FIG. D-39

FABRIC FIBER OPTIC
STRAIN INSTRUMENTATION - LINE 1
2ND LEVEL - FABRIC # 13003 WRAPPED

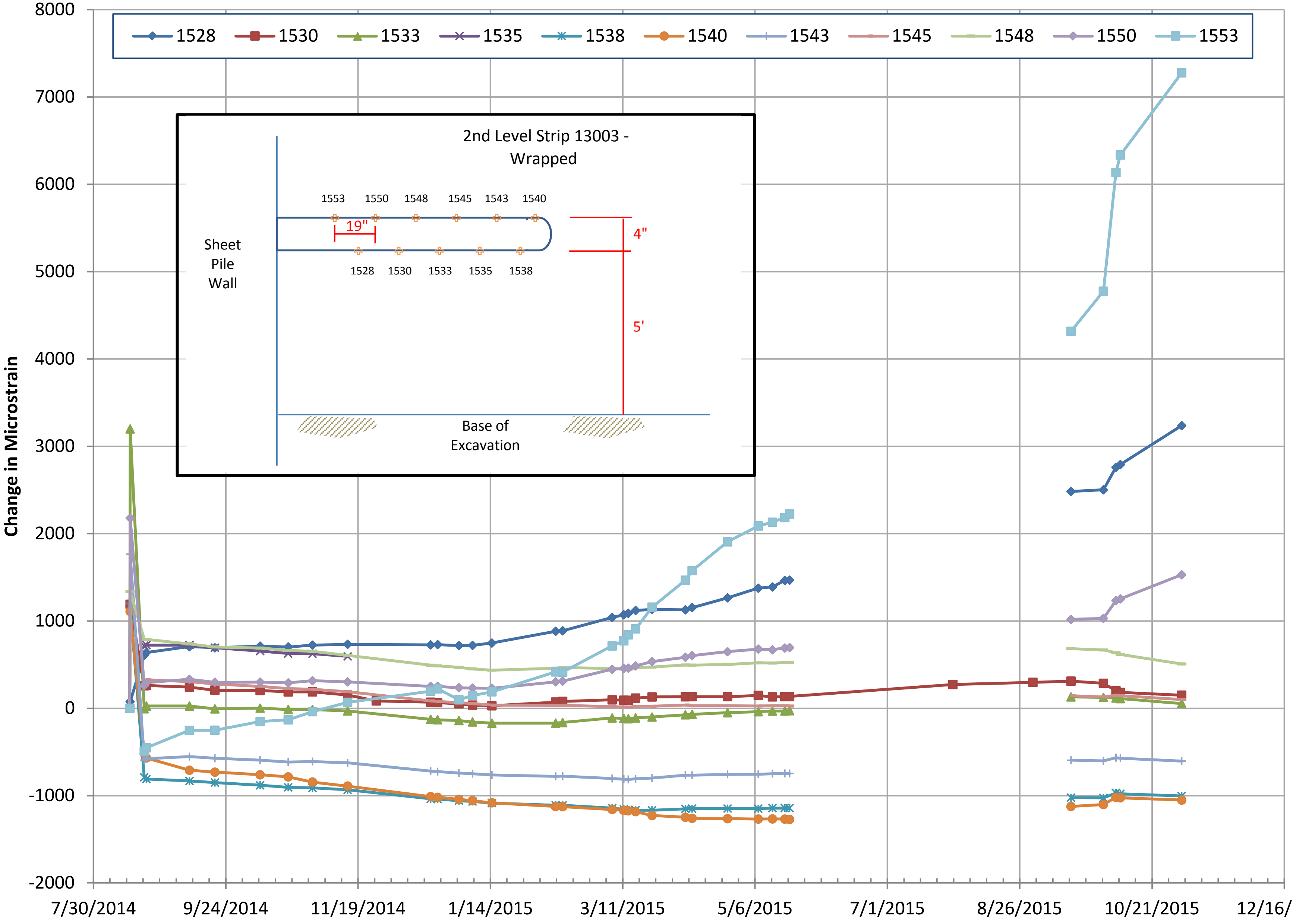


FIG. D-40

FABRIC FIBER OPTIC
STRAIN INSTRUMENTATION - LINE 1
3RD LEVEL - FABRIC # 13004B

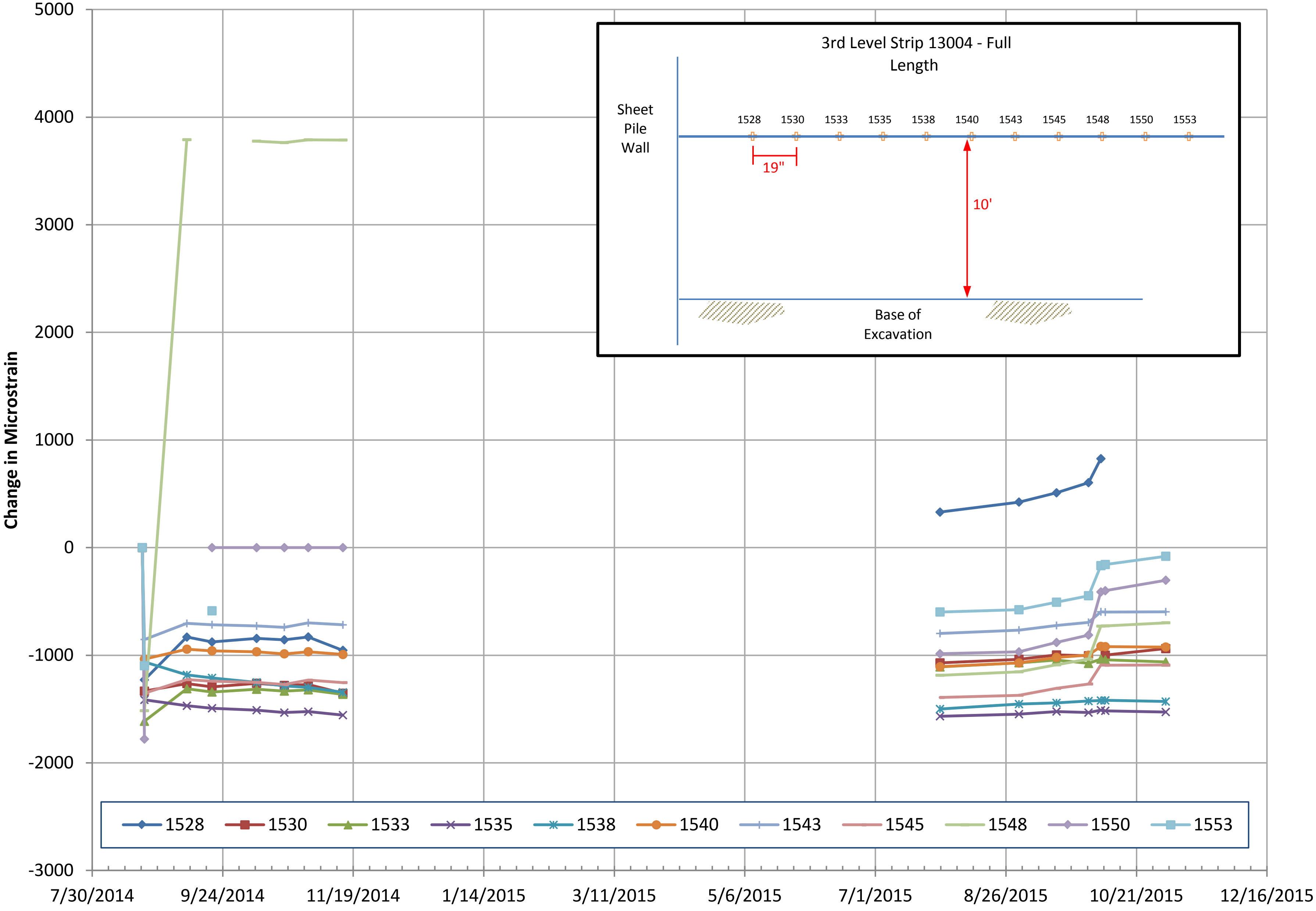


FIG. D-41

FABRIC FIBER OPTIC
STRAIN INSTRUMENTATION - LINE 1
3RD LEVEL - FABRIC # 13005 WRAPPED

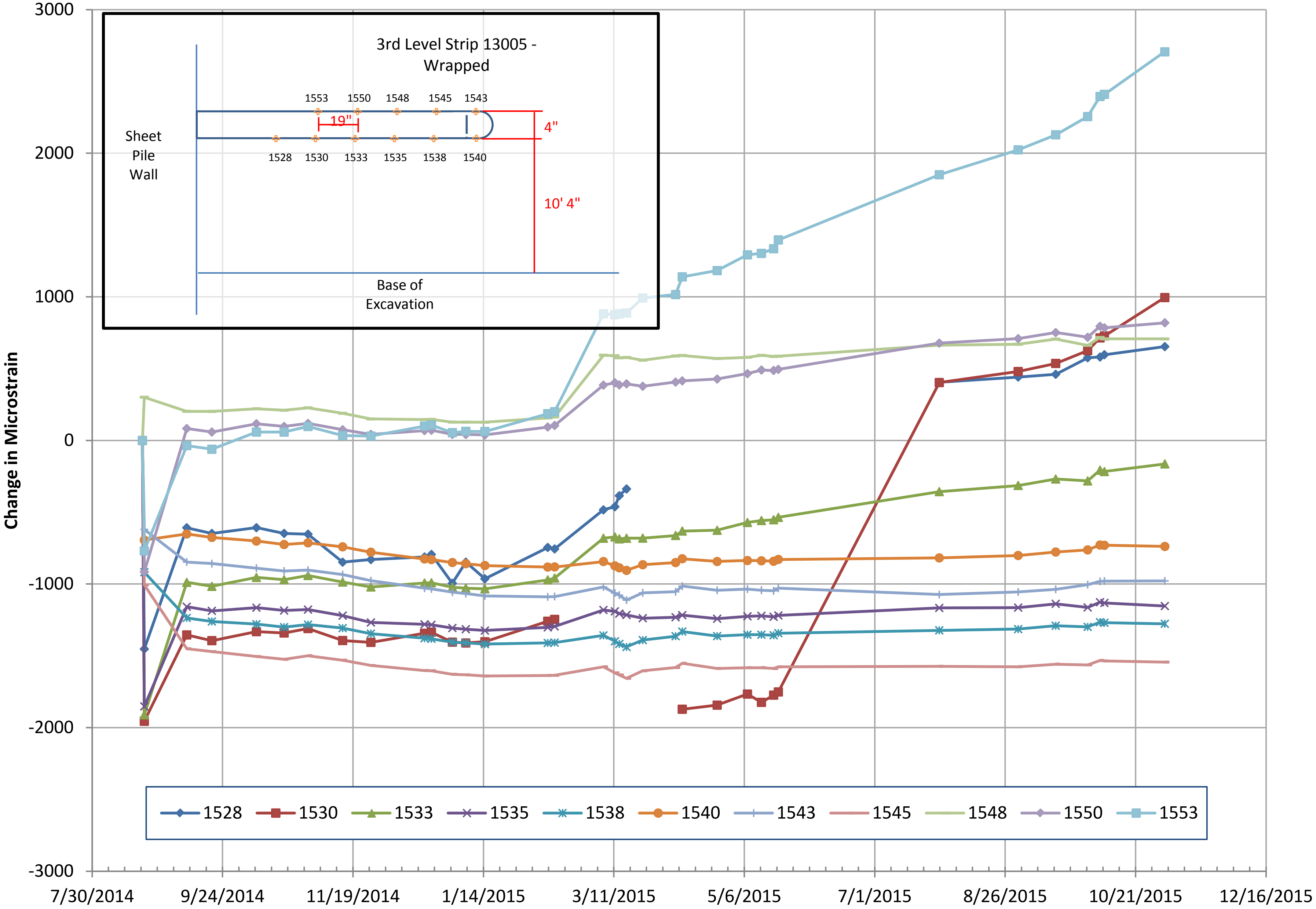


FIG. D-42

FABRIC FIBER OPTIC
STRAIN INSTRUMENTATION - LINE 1
4TH LEVEL - FABRIC # 13022

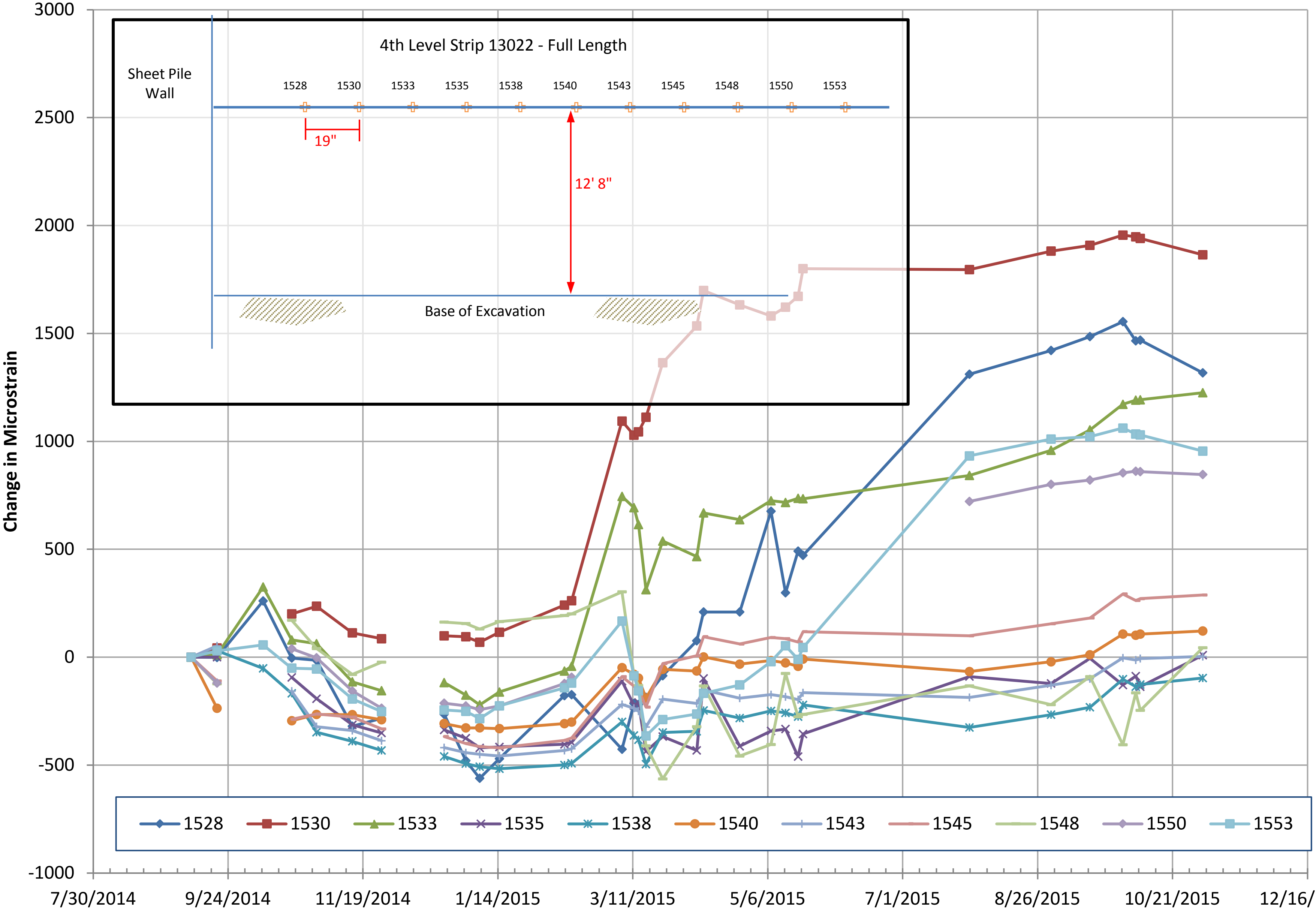
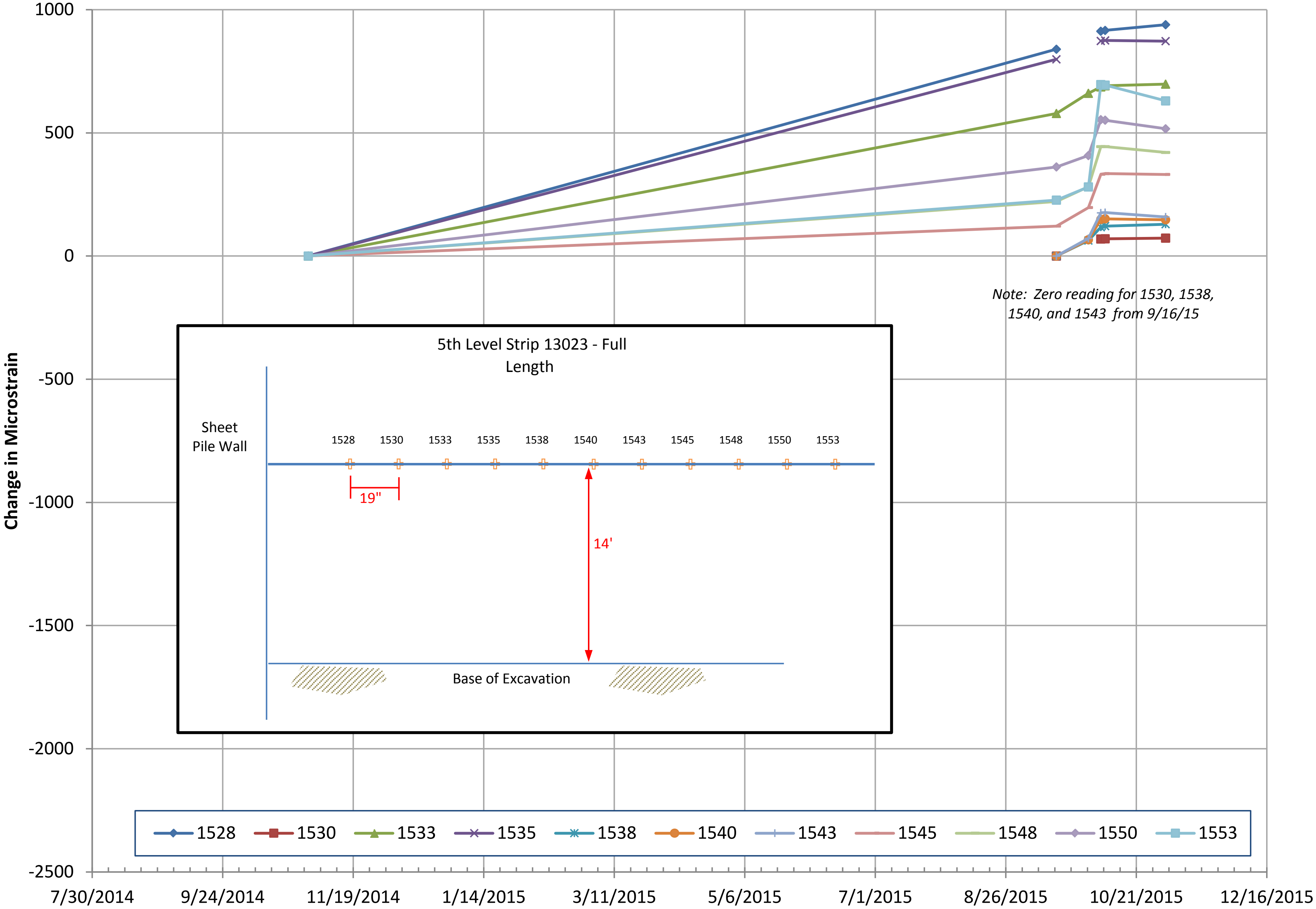


FIG. D-43

FABRIC FIBER OPTIC
STRAIN INSTRUMENTATION - LINE 1
5TH LEVEL - FABRIC # 13023



Note: Zero reading for 1530, 1538, 1540, and 1543 from 9/16/15

FIG. D-44

FABRIC FIBER OPTIC
STRAIN INSTRUMENTATION - LINE 3
LOWER LEVEL - FABRIC # 13021

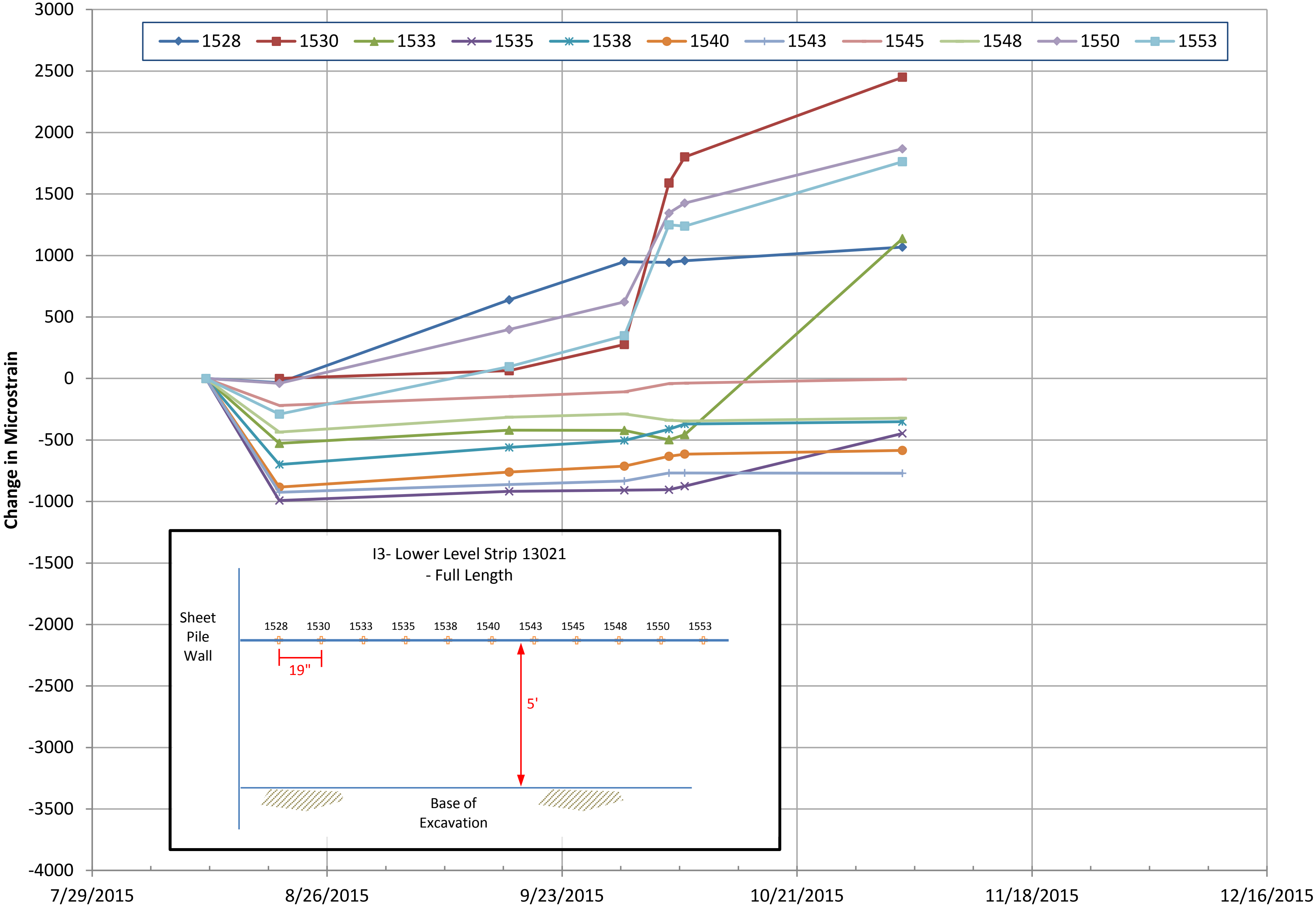


FIG. D-45

FABRIC FIBER OPTIC
STRAIN INSTRUMENTATION - LINE 3
UPPER LEVEL - FABRIC # 13026

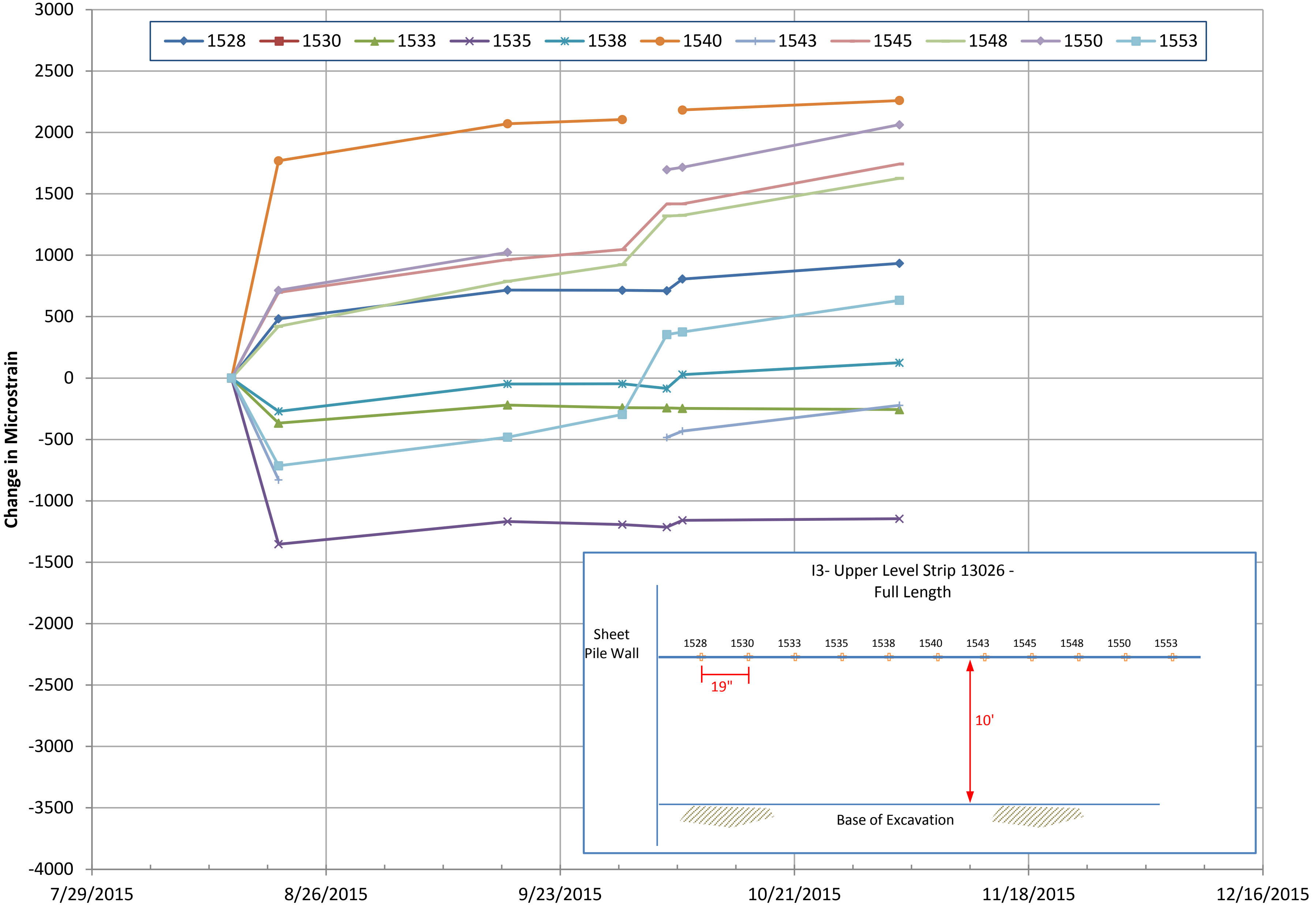


FIG. D-46

APPENDIX E – IMPORTANT INFORMATION ABOUT YOUR GEOTECHNICAL REPORT

SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants

Attachment to and part of Report 23-1-01395-001

Date: February, 2016
To: CDOT Geohazard Program

IMPORTANT INFORMATION ABOUT YOUR GEOTECHNICAL REPORT

CONSULTING SERVICES ARE PERFORMED FOR SPECIFIC PURPOSES AND FOR SPECIFIC CLIENTS.

Consultants prepare reports to meet the specific needs of specific individuals. A report prepared for a civil engineer may not be adequate for a construction contractor or even another civil engineer. Unless indicated otherwise, your consultant prepared your report expressly for you and expressly for the purposes you indicated. No one other than you should apply this report for its intended purpose without first conferring with the consultant. No party should apply this report for any purpose other than that originally contemplated without first conferring with the consultant.

THE CONSULTANT'S REPORT IS BASED ON PROJECT-SPECIFIC FACTORS.

A geotechnical/environmental report is based on a subsurface exploration plan designed to consider a unique set of project-specific factors. Depending on the project, these may include: the general nature of the structure and property involved; its size and configuration; its historical use and practice; the location of the structure on the site and its orientation; other improvements such as access roads, parking lots, and underground utilities; and the additional risk created by scope-of-service limitations imposed by the client. To help avoid costly problems, ask the consultant to evaluate how any factors that change subsequent to the date of the report may affect the recommendations. Unless your consultant indicates otherwise, your report should not be used: (1) when the nature of the proposed project is changed (for example, if an office building will be erected instead of a parking garage, or if a refrigerated warehouse will be built instead of an unrefrigerated one, or chemicals are discovered on or near the site); (2) when the size, elevation, or configuration of the proposed project is altered; (3) when the location or orientation of the proposed project is modified; (4) when there is a change of ownership; or (5) for application to an adjacent site. Consultants cannot accept responsibility for problems that may occur if they are not consulted after factors which were considered in the development of the report have changed.

SUBSURFACE CONDITIONS CAN CHANGE.

Subsurface conditions may be affected as a result of natural processes or human activity. Because a geotechnical/environmental report is based on conditions that existed at the time of subsurface exploration, construction decisions should not be based on a report whose adequacy may have been affected by time. Ask the consultant to advise if additional tests are desirable before construction starts; for example, groundwater conditions commonly vary seasonally.

Construction operations at or adjacent to the site and natural events such as floods, earthquakes, or groundwater fluctuations may also affect subsurface conditions and, thus, the continuing adequacy of a geotechnical/environmental report. The consultant should be kept apprised of any such events, and should be consulted to determine if additional tests are necessary.

MOST RECOMMENDATIONS ARE PROFESSIONAL JUDGMENTS.

Site exploration and testing identifies actual surface and subsurface conditions only at those points where samples are taken. The data were extrapolated by your consultant, who then applied judgment to render an opinion about overall subsurface conditions. The actual interface between materials may be far more gradual or abrupt than your report indicates. Actual conditions in areas not sampled may differ from those predicted in your report. While nothing can be done to prevent such situations, you and your consultant can work together to help reduce their impacts. Retaining your consultant to observe subsurface construction operations can be particularly beneficial in this respect.

A REPORT'S CONCLUSIONS ARE PRELIMINARY.

The conclusions contained in your consultant's report are preliminary because they must be based on the assumption that conditions revealed through selective exploratory sampling are indicative of actual conditions throughout a site. Actual subsurface conditions can be discerned only during earthwork; therefore, you should retain your consultant to observe actual conditions and to provide conclusions. Only the consultant who prepared the report is fully familiar with the background information needed to determine whether or not the report's recommendations based on those conclusions are valid and whether or not the contractor is abiding by applicable recommendations. The consultant who developed your report cannot assume responsibility or liability for the adequacy of the report's recommendations if another party is retained to observe construction.

THE CONSULTANT'S REPORT IS SUBJECT TO MISINTERPRETATION.

Costly problems can occur when other design professionals develop their plans based on misinterpretation of a geotechnical/environmental report. To help avoid these problems, the consultant should be retained to work with other project design professionals to explain relevant geotechnical, geological, hydrogeological, and environmental findings, and to review the adequacy of their plans and specifications relative to these issues.

BORING LOGS AND/OR MONITORING WELL DATA SHOULD NOT BE SEPARATED FROM THE REPORT.

Final boring logs developed by the consultant are based upon interpretation of field logs (assembled by site personnel), field test results, and laboratory and/or office evaluation of field samples and data. Only final boring logs and data are customarily included in geotechnical/environmental reports. These final logs should not, under any circumstances, be redrawn for inclusion in architectural or other design drawings, because drafters may commit errors or omissions in the transfer process.

To reduce the likelihood of boring log or monitoring well misinterpretation, contractors should be given ready access to the complete geotechnical engineering/environmental report prepared or authorized for their use. If access is provided only to the report prepared for you, you should advise contractors of the report's limitations, assuming that a contractor was not one of the specific persons for whom the report was prepared, and that developing construction cost estimates was not one of the specific purposes for which it was prepared. While a contractor may gain important knowledge from a report prepared for another party, the contractor should discuss the report with your consultant and perform the additional or alternative work believed necessary to obtain the data specifically appropriate for construction cost estimating purposes. Some clients hold the mistaken impression that simply disclaiming responsibility for the accuracy of subsurface information always insulates them from attendant liability. Providing the best available information to contractors helps prevent costly construction problems and the adversarial attitudes that aggravate them to a disproportionate scale.

READ RESPONSIBILITY CLAUSES CLOSELY.

Because geotechnical/environmental engineering is based extensively on judgment and opinion, it is far less exact than other design disciplines. This situation has resulted in wholly unwarranted claims being lodged against consultants. To help prevent this problem, consultants have developed a number of clauses for use in their contracts, reports and other documents. These responsibility clauses are not exculpatory clauses designed to transfer the consultant's liabilities to other parties; rather, they are definitive clauses that identify where the consultant's responsibilities begin and end. Their use helps all parties involved recognize their individual responsibilities and take appropriate action. Some of these definitive clauses are likely to appear in your report, and you are encouraged to read them closely. Your consultant will be pleased to give full and frank answers to your questions.

The preceding paragraphs are based on information provided by the
ASFE/Association of Engineering Firms Practicing in the Geosciences, Silver Spring, Maryland