REPORT

Steel sheet piles as measures against rapid mass flows

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NORWEGIAN GEOTECHNICAL INSTITUTE
NGI.NO

Project

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Client:	Vegagerðin/The Icelandic Road and Coastal Administration (IRCA) and NGI (GBV2015)
Client contact person:	Þórir Ingason
Contract reference:	IRCA: email, 4 March 2014; NGI: email, 17 December 2014

for NGI

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Summary

Steel sheet piles have been used for mitigation against small snow avalanches and rock falls for over twenty years in Iceland in areas with limited space for other types of mitigation measures at road sides. Those approx. 3 m high structures have proved to be useful and have resulted in fewer road closures.

Little is known about the forces that avalanche or rock falls exert to these structures and it hampers further development. For this reason, the Icelandic Road and Coastal Administration (IRCA) and the Norwegian Geotechnical Institute (NGI) decided to instrument one such wall in north Iceland.

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Review and reference page

1 Introduction

Narrow fjords with steep mountainsides are a challenge for road safety in Iceland, Norway and many other mountainous countries. Conventional mitigation measures in the run-out zone, like dams, are usually not applicable due to limited space. Supporting structures in the starting zone are in many cases too expensive in relation to the traffic volume of the road. Therefore space-saving structures are needed.

While steel sheet piles are well known as a wall material in piers and in excavations in loose and unstable soil, there are virtually no reports on their use in mitigation against rapid mass movements. However, for over twenty years steel sheet piles have been used to protect road sections in Iceland against small snow avalanches and rock falls. These typically 3 m high structures have proved to be useful and have resulted in fewer road closures even though the snow cloud and part of the dense part can overtop the sheet wall. Larger/higher structures to stop larger avalanches are feasible.

Little is known about the forces that avalanches or rock falls exert on the steel sheet piles and how the latter react to these loads. Yet good control over this is necessary for ensuring the serviceability of the walls and optimizing their design also with respect to cost. For this reason, the Icelandic Road and Coastal Administration (IRCA) and the Norwegian Geotechnical Institute (NGI) decided to instrument one such wall in north Iceland.

The work presented here is a joint work of Árni Jónsson from NGI, Guðmundur Heiðreksson at Vegagerðin (The Icelandic Road and Coastal Administration, IRCA) Akureyri Iceland, and Torfi B. Jóhannesson og Magnús Steinarsson at MogT ehf, Iceland.

The authors applied for funding to the IRCA research fund in early 2014 (grant 1800-483) and later in 2014 NGI participated in the research funding (grant 1B1).

2 The location of the test site

Figures 1 and 2 give an overview of the test site location.

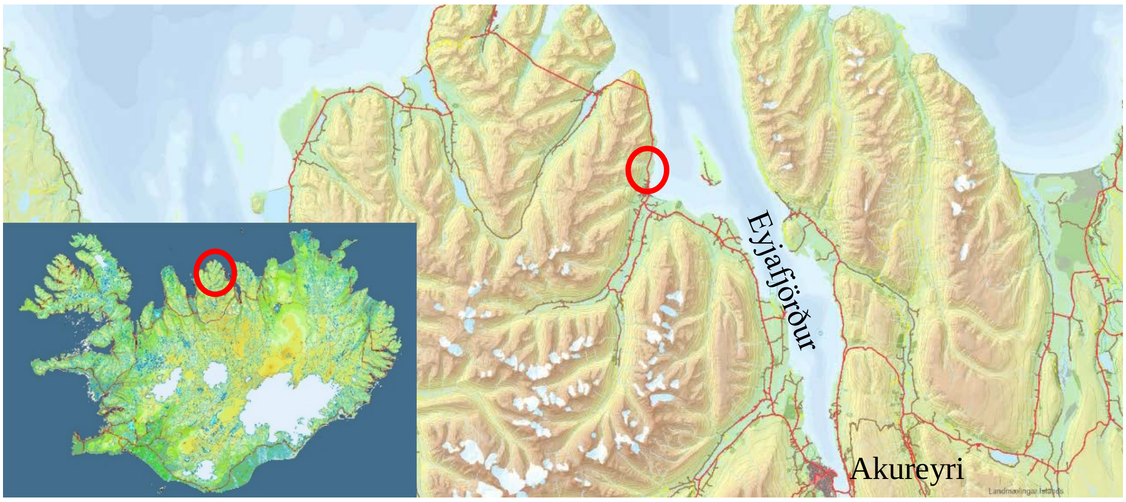


Figure 1. Red circle shows the location of the test site north of Sauðanes. Map: LMI.is.

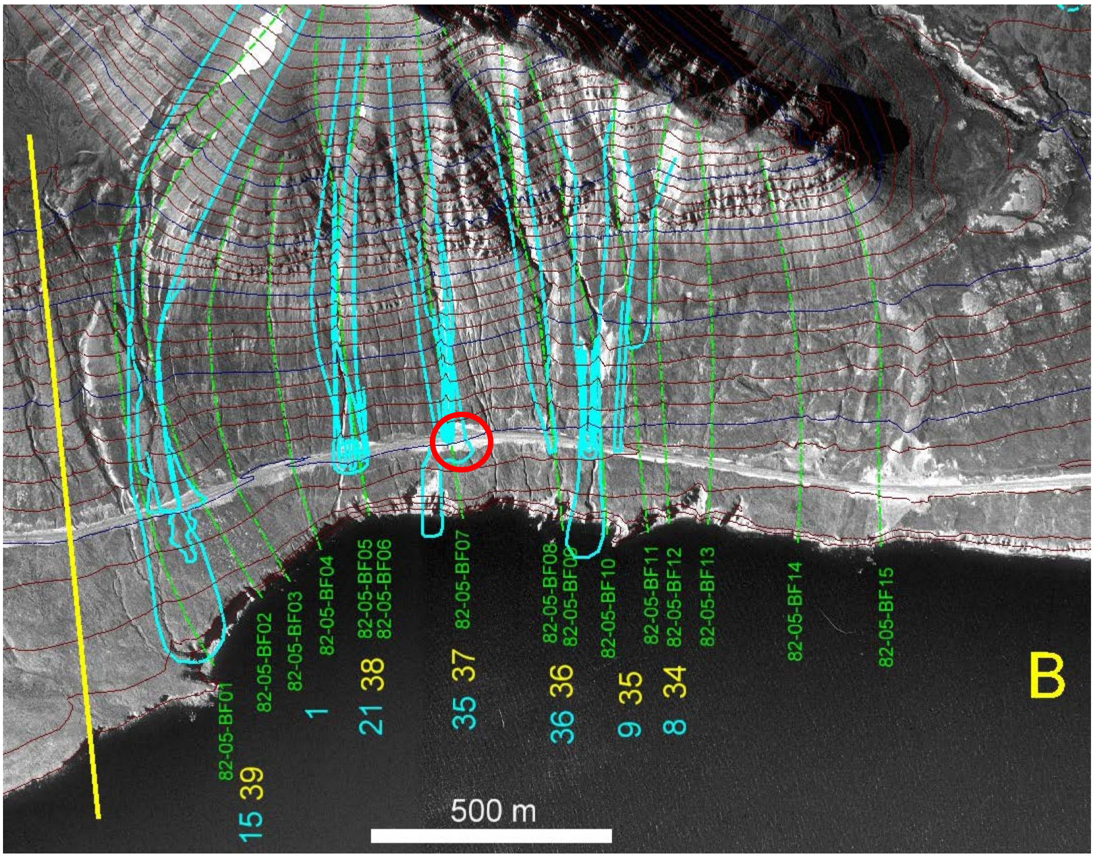


Figure 2. Avalanche paths and registered avalanches (cyan lines) north of Sauðanes. Red circle denotes the test site. Yellow numbers show the IRCA avalanche path numbering system. Cyan numbers show number of avalanches for the period 1974-2000. Green numbers and paths show paths used in [1]. Aerial photo: LMI.

3 The aim of the project

Steel sheet piles are well known as a wall material in piers and in excavations in loose and unstable soil and the design methods are well-known for these applications. For over 20 years steel sheet piles have been used, as wall material in small catching dams/walls at the road side in Oshlíð between Hnífsdalur and Bolungarvík in the Westfjords Iceland. According to the IRCA personnel these sheet pile walls have proved to be able to stop small snow avalanches and rockfalls and they have increased the traffic safety considerably. Unfortunately no registration of the frequency, size or date is available for these incidents. Steel sheet pile walls are not meant to stop large avalanches or big boulders, but the smaller and frequent incidents that pose a constant threat and disturbance to road users.

When IRCA considered improvement of the road-users safety on state highway no 82, between Dalvík and Ólafsfjörður steel sheet piles were considered to be the best way to increase the road safety against snow avalanches and rock fall. Several locations on this road are threatened by those events but the area north of Sauðanes (Figure 2 and Figure 3) is considered to be one of the worst locations [1].

The steel sheet pile wall is a so-called cantilever wall, i.e. part of the steel sheet piles is excavated into the ground, which holds them in place. The passive resisting capacity of the soil below the depth of excavation prevents overturning.

Little is known about the forces that avalanches or rock falls exert on cantilever steel sheet piles and how the latter reacts to these loads. The purpose of this project is to measure forces on the sheet piles while snow avalanches and/or rolling boulders hit the wall. The goal is to use the information to improve the design of these walls and to find out if it is possible to make them larger (higher) in order to stop larger avalanches. Knowledge of impact forces plays an important role in this study.

4 The steel sheet pile wall and the excavation behind it

Figure 3. The sheet pile wall in avalanche path no 37.

In [1] a preliminary design information was given on the mitigation measure for these three avalanche paths. The main concept was an excavated area and a wall close to the road. The purpose of the excavated area is twofold, a) to ensure that the avalanche will hit the bottom of the excavated area for energy dissipation before it hits the wall, b) to store most of the snow masses of the avalanche. The purpose of the wall was to stop the part of the avalanche that would continue in horizontal direction towards the road after impact. This is the theoretical function of this system but the real thing is not so simple as shortly after the front of the avalanche hits the bottom of the excavated area the avalanche debris gradually fills up the area, which then leads to that the latter part of the avalanche can hit the wall directly depending on the volume of the avalanche.

The earthwork and sheet piling was carried out in summer and fall of 2011 by a local contractor. Two walls of 40 m were built (avalanche paths 35 and 36) and 50 m wall for avalanche path 37 (monitored). It was estimated that 8000 to 10000 m³ of rock had to be removed. All excavated material was used to widen the shoulder of the road on the opposite side.

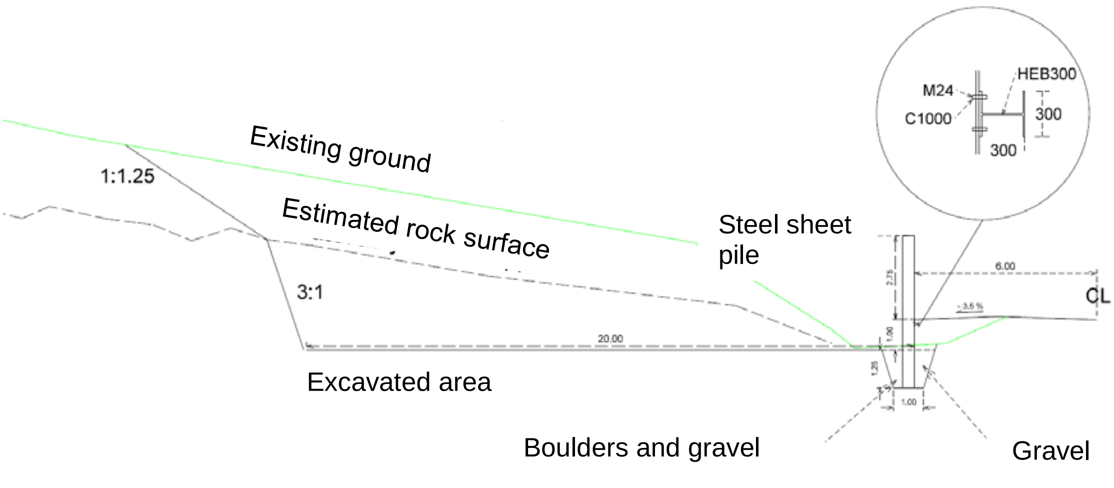


Figure 4. Typical cross section from the IRCA bid documents.

The location of the steel sheet pile wall is 6 m from the centreline of the road and the height is 2.75 m from the new shoulder surface (Figure 4). During construction the walls at avalanche paths 35 and 36 had to be moved to approx. 8 m due to power cable at road side.

On the inside/impact side the height of the wall is 3.75 m and the depth of the excavated area is 20 m from the wall. A trench was dug into the ground, partly in rock and partly in soft soil. The 5.25 m long steel sheet pile was then placed into the trench and the trench was filled with boulders and compacted gravel. On the outside the steel sheet pile was reinforced with HEB 300 beam just below the new ground surface to ensure the rigidity of the wall.

Figure 5. Installation of the steel sheet piles. Here the steel sheet piles are guided by steel pipes while the trench is filled with boulders and gravel. Photo: IRCA.

The steel sheet piles were delivered to the project by IRCA. The following table shows the steel sheet pile data:

Table 1. Steel sheet pile data.

Type	Width	Height	Thickness	Weight	Weight	Section Modulus	Moment of Inertia
	mm	mm	mm	kg/m	kg/m2	cm3/m	cm4/m
WRZ21-685	685	402	10	85.7	125.2	2055	41304

After completion of the work the contractor discussed this installation method (Figure 5) with the IRCA. The conclusion was that it would have been easier to fill the trench with compacted gravel and then push the steel sheet piles into the gravel/trench.

5 Monitoring instruments and installation

The monitoring system consists of seven strain gauges and a logger all located on the outside/downslope of the wall. The location of the strain gauges is as follows, measured from ground surface (+) up and (–) in the ground (Figure 6): 251cm, 164cm, 77cm, -10 cm, -97cm. To the sides the strain gauges are -10 cm in the ground on the fifth sheet pile to the left and right from the centre line.

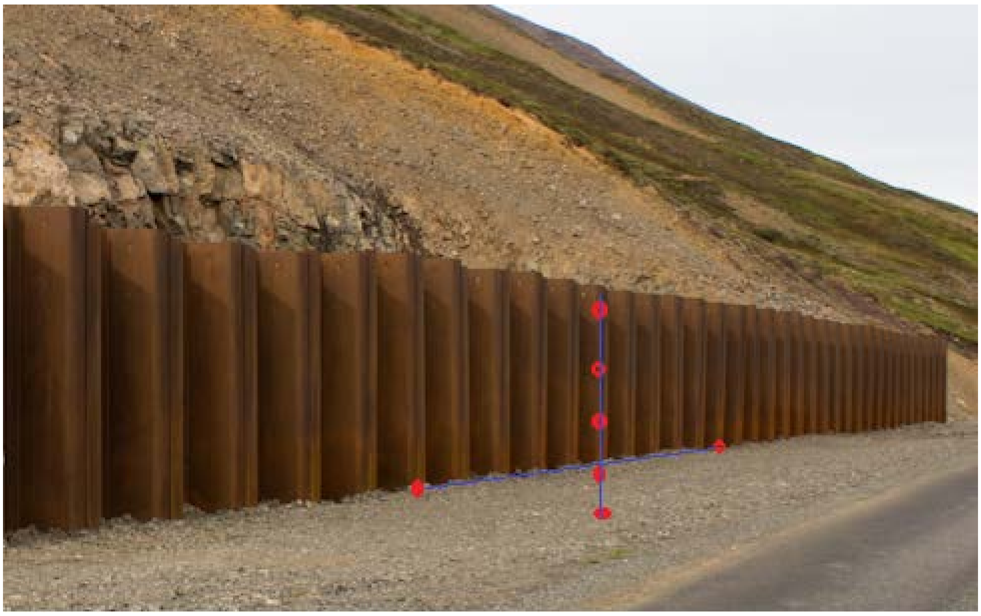


Figure 6. Red dots indicates the location of the strain gauges. The four dots seen on the ground indicate strain gauges in the ground.

The strain gauges are of type S-BOS from Procter & Chester Measurements, further details about the strain gauges is in Appendix B. Two bolts were welded to the steel sheet pile and the strain gauges fastened to the bolts. Then a shield was placed over the strain gauges to prevent them from damaging from external forces like snow from the snow plough trucks. The cables from the sensors were feed through a protecting tubes up to the cabinet where they were connected to the data logger.

The logging unit is a CR5000 Measurement & Control System from Campell Scientific. The data logger is a selfcontained, low power, rugged datalogger that is capable of a maximum throughput of 5 kHz. Standard operating range is -25° to +50°C. There is a 16GB PCMCIA memory card in the logger for storing the measurements. Each sensor is polled 227 time a second. Further details about the data logger are in Appendix C.

This system is powered by two 100Ah AGM batteries and one 100W solar cell.

At the end of the installation of the steel sheet piles the function of the strain gauges was tested by pulling the steel sheet piles by a 3 ton jeep. The result is shown in Figure 7. A more detailed calibration has to be done in the coming months.

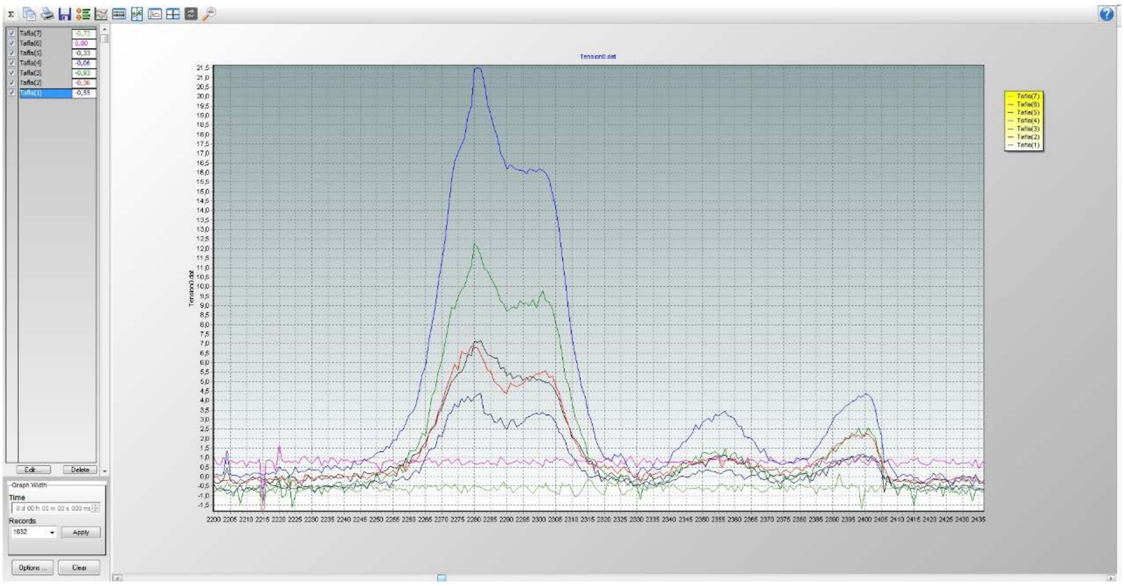


Figure 7. Test data from a pull of a 3 ton vehicle. The figure show data from 7 strain gauges.

If the tension in strain gauge no 4 (from top and down) exceeds a threshold value data at a sample rate of 1589 Hz from 10 seconds before until 20 seconds after the triggering are stored to a memory card in the logger. The reason for this limited storing time is to limit the volume of logged information on site and also to limit the volume of data sent via 3G mobile phone to Kópavogur where the server is. The server in Kópavogur calls the logger regularly to check if new data has been stored on the memory card and if so the data is downloaded.

6 The winter 2014/2015

So far no incident has been registered after the installation of the instruments. The winter had relatively little precipitation and unlike the previous winters avalanches did not reach the steel sheet piles and nor did the boulders.

7 Future work

In our application for this research work we planned for two years monitoring and then final reporting but as no incident was registered the winter 2014/2015 it seems reasonable to extend the monitoring at least one more winter. This will be discussed with the IRCA and NGI in the fall of 2015.

8 Acknowledgments

The authors would like to thank the research funds at IRCA and NGI for their support.

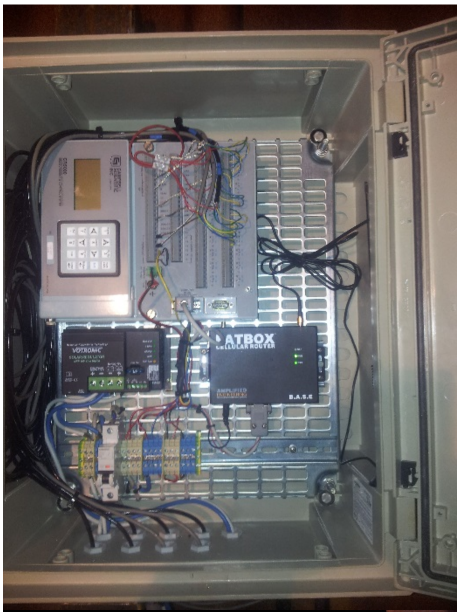
9 References

1. ORION Consulting. (2007). ÓLAFSFJARÐARVEGUR (82), DALVÍK – ÓLAFSFJÖRÐUR. Greinargerð um snjóflóð, snjóflóðahættu og tillögur um varnaraðgerðir. (e: Report on snow avalanches, snow avalanche danger and proposed mitigation measures).

Appendix A

PHOTO FROM THE INSTALLATION WORK

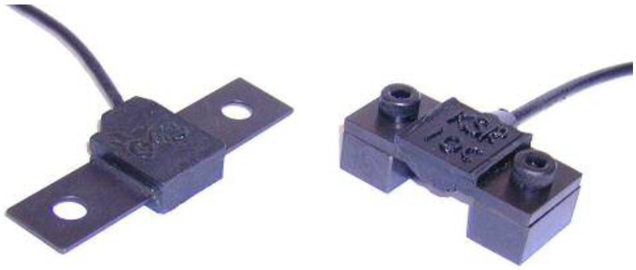

EXIDE
MARINE & MULTIFIT
DUAL AGM
EP 900
EXIDE
MARINE & MULTIFIT
DUAL AGM
EP 900


ATBOX
CELLULAR ROUTER

Appendix B

STRAIN GAUGE DATA SHEET

S-BOS - Bolt On Sensor



FEATURES

- Sealed to IP65.
- Custom build dimensions available.

APPLICATIONS

- Overload and protection.
- Overload protection for front end loaders.

DESCRIPTION

The S-BOS is a simple sensor that locates onto a steel structure and monitors the strain that is directed through it. Consideration must be taken on the application and the positioning of the S-BOS for successful measurement to be taken. This sensor is not recommended for level measurements on silos.

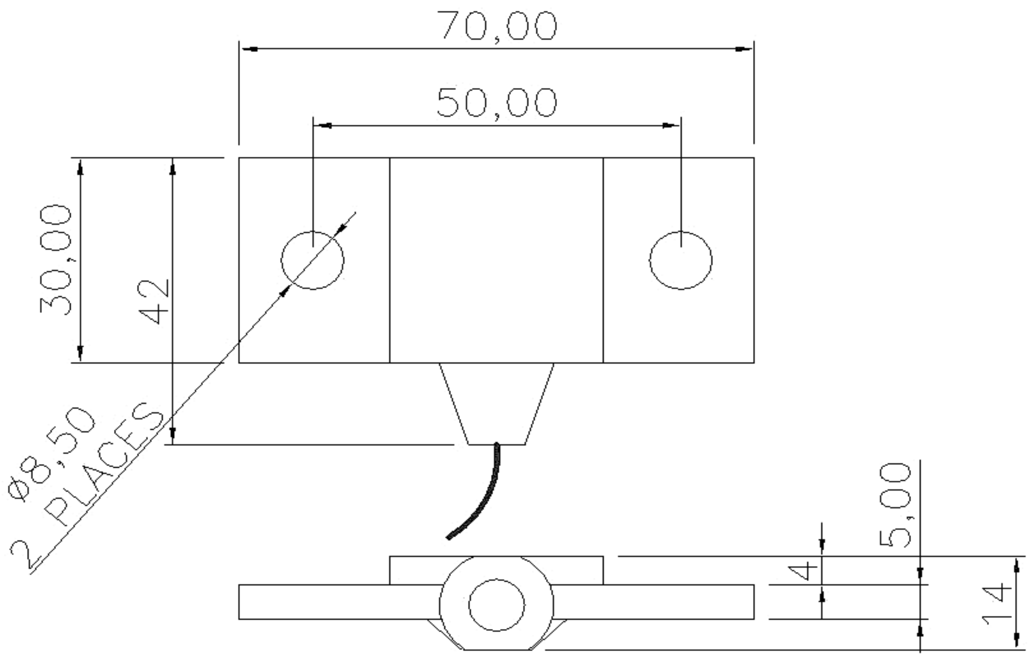
If the dimensions or specifications shown do not satisfy your requirements, please contact us and our in-house design and build team should be able to create a solution for your application.

TYPICAL SPECIFICATION

PARAMETER	VALUE	UNITS
Capacity	±500	με
Rated Output	0.7 nom	mV/V
Linearity and Non Repeatability	1	±% of Rated Output
Zero Balance	1.5	±% of Rated Output
Temperature Range: Operating	-30 to +80	°C
Temperature Effect: On Zero	0.02	±% of Rated Load/°C
Safe Overload	150	% of Rated Capacity
Ultimate Overload	300	% of Rated Capacity
Excitation: Recommended Excitation: Maximum	10 15	Volts AC or DC
Input Impedance	350 nom	Ω
Output Impedance	350 nom	Ω
Insulation Resistance	>2	GΩ at 50VDC
Construction	Blacked Alloy Steel	
Environmental Protection	IP65	
Cable	5m *(4 core screened)*	

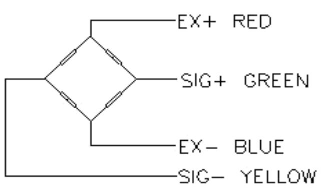
S-BOS - Bolt On Sensor

OUTLINE DIMENSIONS in millimetres



NOTE: If the dimensions or specification do not suit, PCM have an in-house design and build service that should satisfy your requirements.

WIRING DETAIL

DYNAMOMETER	OUTPUT	CABLE
	EXCITATION+ SENSE + EXCITATION - OUTPUT- SENSE - OUTPUT+ ----------------------	*Blue* *Green* *Black* *Red* *Brown* *White*

www.pcm-uk.com
Email: sales@pcm-uk.com
Tel: +44 (0) 1926 864444
Fax: +44 (0) 1926 864888

Appendix C

CR5000 MEASUREMENT & CONTROL SYSTEM
(DATA LOGGER)

CAMPBELL® SCIENTIFIC
WHEN MEASUREMENTS MATTER

CR5000

Measurement & Control System

A rugged,

high-performance

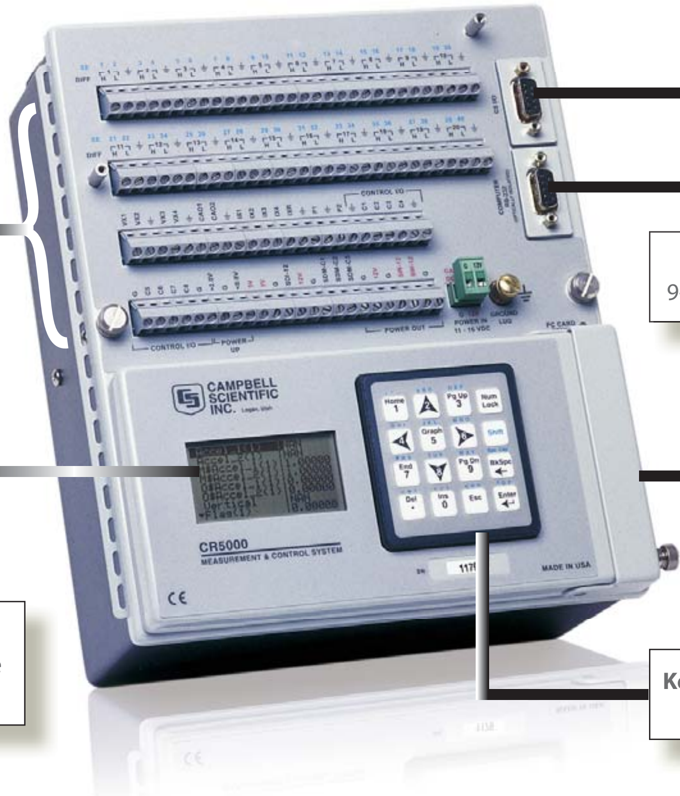
data acquisition

system

CR5000 Measurement and Control System

The CR5000 Measurement and Control System is a self-contained, low power, rugged datalogger that is capable of a maximum throughput of 5 kHz. Standard operating range is -25° to +50°C; an optional extended range of -40° to +85°C is available.

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



CS I/O Port—connects data transfer peripherals.

Computer RS-232—provides a 9-pin electrically isolated DCE port.

PCMCIA Card Slot—accepts a single Type I, Type II, or Type III card or the CFI adapter and a CompactFlash card.

128 x 64 Backlit LCD—provides a graphical or 8-line numeric data display.

Keyboard—allows on-site program editing and command entries.

Design Features

- Stand-alone unit offering high performance and an environmentally rugged design
- Maximum throughput of 2k to 5k measurements per second (configuration dependant)
- Powerful instruction set that supports measurement of most sensor types, on-board processing, data reduction, and intelligent control
- Backlit display allowing numerical or graphical display of stored data
- PCMCIA card slot for extended data storage and transporting data to a PC
- Battery-backed SRAM memory and clock ensuring data, programs, and accurate time are maintained while the CR5000 is disconnected from its main power source
- Robust ESD protection
- Low power, 12 Vdc operation
- Data values stored in tables with a time stamp and record number

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. These instructions include averages, maximums, minimums, standard deviations, histograms, rainflow histograms, level crossings, and Fast Fourier Transfers (FFTs).

Data Storage Capacity

Data and multiple programs are stored on-board in battery-backed SRAM. Data is stored in a table format. Up to 900,000 low-resolution data points can be stored in its CPU memory. Storage capacity can be increased by using a PC or CompactFlash card.

Input Output Terminals

Analog Inputs
Twenty differential (40 single-ended) input channels support five full-scale ranges (±20 mV to ±5000 mV) at 16-bit measurement resolution. Larger signal voltages are accommodated with precision 2:1 and 10:1 input voltage divider modules.

Pulse Counters
Two 16-bit pulse channels count switch closures, low level ac pulses, and high frequency square waves.

Switched Excitation Outputs
Four switched voltage and four switched current outputs provide precision excitation for ratiometric sensor/bridge measurements.

Digital I/O Ports
Eight ports have multiple functions including digital control output, interrupt, pulse counting, switch closure, frequency/period measurements, and edge timing communication. One other port is dedicated for SDI-12 measurements, and three additional ports are dedicated for measuring SDM devices.

Continuous Analog Outputs
Two continuous analog outputs provide voltage levels to displays or proportional controllers.

RS-232 Port
The RS-232 port is for connecting a PC, serial sensor, or RS-232 modem. The PC attaches to the CR5000 via an RS-232 cable—no interface required. This port isolates the PC's electrical system from the datalogger, thereby protecting against ground loops, normal static discharge, and noise.

CS I/O Port
Many communication devices connect with the CR5000 via this port. A PC may also connect with this port, but an SC32B or SC-USB interface is required.

Power Connections
The continuous 5 V and 12 V terminals are for connecting sensors and non-Campbell Scientific peripherals. Two switched 12 V terminals are program controlled.

Transient Protection

Rugged gas tubes protect all terminal block inputs and outputs from electrical transients. The CR5000 is CE compliant under the European Union's EMC Directive.

PCMCIA Card Slot

The PCMCIA card slot supports one Type I, Type II, or Type III PC Card or the CF1 adapter and one CompactFlash (CF) card. The card can be used to expand the CR5000's storage capacity or transport data or programs to a PC.

The storage capacity of Type II cards exceeds 1 GB. Type III cards provide data storage capacities exceeding 1 GB but may not be suitable for all environments. Campbell Scientific offers CF cards that store up to 2 GB of data.

Enclosures

The CR5000 can be housed in an ENC14/16 and ENC16/18 enclosure. A CR5000 housed in a weather-resistant enclosure can collect data under extremely harsh conditions. The enclosure protects the CR5000 from dust, water, sunlight, or pollutants. An internal mounting plate is prepunched for easy system configuration and exchange of equipment in the field.

Operating Temperature Ranges

Standard operating range is -25° to +50°C; an extended range of -40° to +85°C is available. The rechargeable battery base has a different temperature range (see below).

Battery Base Options

Rechargeable Base
The rechargeable base includes an internal 7-Ah sealed rechargeable battery that can be charged from vehicle power, solar panels, or ac power. Operating temperature range is -40° to +60°C.

When using vehicle power, our DCDC18R Boost Regulator is used to increase the vehicle's supply voltage to charging levels required by the CR5000.

Low-Profile Base (no battery)
The low-profile base requires a user-supplied dc source. It is preferred when the system's power consumption needs a larger capacity battery or when it's advantageous to have a thinner, lighter datalogger.

Data Storage and Retrieval 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 CR5000's integrated keyboard display is used to program the datalogger, manually initiate data transfer, and display data. It displays 8 lines x 21 characters (64 x 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".

Direct Links

A PC or laptop can be connected directly to the datalogger's RS-232 port (no interface required). This port provides optical isolation. Alternatively, the PC or laptop can be connected to the CR5000's CS I/O port via an SC32B or SC-USB interface.

PC Cards or CF Cards

The CR5000 can store data and programs on a PC card or CF card. The card can then be carried to a computer. The computer directly reads PC cards via its PCMCIA card slot. CF cards are read using either a CF1 adapter or the 17752 Reader/Writer. Please note that the CF card should be industrial-grade with a storage capacity of 2 GB or less.

Ethernet

The NL100 interface enables a CR5000 datalogger to communicate over a local network or a dedicated Internet connection via TCP/IP.

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).

Multidrop Interface

The MD485 intelligent RS-485 interface allows a PC to address and communicate with one or more dataloggers over a single two-twisted-pair cable. Distances up to 4000 feet are supported.

Spread Spectrum Radios

Spread spectrum radios provide communications between a base station computer and several field sites over short distances. Line-of-sight is required.

Telephone Networks

The CR5000 can communicate with a PC using landlines, cellular CDMA, or cellular GPRS transceivers. Telephone networks can be combined with spread spectrum radios, multidrop modems, and Ethernet interfaces, which extends the distance between datalogger and PC.

Satellite Transmitters

Our NESDIS-certified GOES satellite transmitter supports one-way communications from a Data Collection Platform (DCP) to a receiving station.

A GOES satellite system transmits data from a remote weather station in Nevado Sajama, Bolivia, to climate researchers in the United States.

Channel Expansion

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 CR5000 is 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-CAN (left of CR5000) allows a vehicle's on-board diagnostic system to output standardized data streams that are synchronized with other measurements and stored in the CR5000.

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 CR5000 programs in four easy steps. PC200W allows customers to transfer a program to, or retrieve data from a CR5000 via a direct communications link.

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

Datalogger Support Software

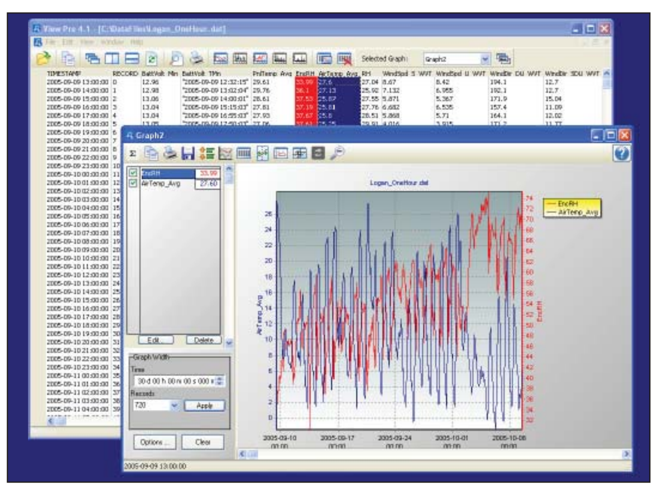
Our datalogger support software packages provide more capabilities than our starter software. These software packages contains program editing, communications, and display tools that can support an entire datalogger network.

Short Cut is available from our website (at no charge) and Resource CD. It is also bundled with PC200W, PC400, LoggerNet, and RTDAQ Software.

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) or scheduled data collection.

RTDAQ is an ideal solution for industrial and real-time users desiring to use reliable data collection software over a single telecommunications medium, and who do not rely on scheduled data collection. RTDAQ's strength lies in its ability to handle the display of high speed data.

LoggerNet is Campbell Scientific's full-featured datalogger support software. It is referred to as "full-featured" because it provides a way to accomplish almost all the tasks you'll need to complete when using a datalogger. LoggerNet supports combined communication options (e.g., phone-to-RF) and scheduled data collection.



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

Applications

Open Path Eddy Covariance Systems

These systems use eddy covariance techniques to calculate water vapor, carbon dioxide, and heat flux.

For eddy covariance applications, the CR5000 can measure the EC150 Open-Path CO_2 Analyzer, CSAT3A Sonic Anemometer, and KH20 Krypton Hygrometer then compute fluxes on-line.

Below are the sensors used and their measurements:

- CSAT3A Sonic Anemometer—absolute wind and sonic temperature fluctuations
- KH20 Hygrometer—fluctuations of atmospheric water vapor
- EC150 Open Path Gas Analyzer—both absolute CO_2 and water vapor
- FW05 Fine Wire Thermocouple—absolute temperature

The CR5000 measures the above sensors and computes fluxes on-line. The raw time-series data can be saved to a PC-card, along with processed data for later analysis. A PC at the site is not required. The CR5000's storage capacity can be increased using PC cards.

Structural and Seismic Monitoring

The CR5000 can be used in applications ranging from simple beam fatigue analysis, to structural mechanics research, to continuous monitoring of large, complex structures. The on-board instruction set supports many algorithms and math functions that are useful for structural and seismic monitoring.

The datalogger can store data as rainflow or level crossing histograms. The rainflow and level crossing algorithms can be processed for extended periods of time, not just a finite number of cycles.

The datalogger's control functions allow it to activate alarms, actuate electrical devices, or shut down equipment based on time or measured conditions.

Typical sensors used for structural and seismic monitoring include:

- Carlson strain meters
- Foil strain gages (set up in quarter, half, or full bridge strain configurations)
- Inclinometers
- Crack and joint sensors
- Tilt sensors
- Piezoresistive accelerometers
- Piezoelectric accelerometers
- Capacitive accelerometers
- Borehole accelerometers
- Servo force balance accelerometers

Cracks in the walls of Castillo de San Marcos, Florida were instrumented to determine their genesis and the best course for corrective action.

Vehicle Monitoring and Testing

The versatile, rugged design and low power requirements of the CR5000 datalogger make it well suited for vehicle monitoring. It excels in cold and hot temperature, high altitude, off-highway, and cross-country performance testing. The CR5000 is compatible with our SDM-CAN interface.

Compatible sensors often used for vehicle monitoring and testing include thermocouples, pressure transducers, GPS receivers, pulse pick-ups, flow transducers, potentiometers, strain gages, load cells, digital switches, accelerometers, LVDTs, and tilt sensors. Most sensors connect directly to the datalogger, eliminating costly external signal conditioning.

Photo courtesy Case Corporation

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

Common measurements include:

- 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, blower currents, ac on/off, refrigerant pressures, time-to-comfort
- Brakes—line pressure, pedal pressure and travel, ABS, fluid and pad temperature
- Engine—pressure, temperature, crank position, RPM, time-to-start, oil pump cavitation
- General vehicle—chassis monitoring, road noise, traction, payload, vehicle position/speed, steering, air bag, hot/cold soaks, wind tunnels, CANbus, wiper speed/current, vehicle electrical loads

Other Applications

- HVAC Systems—measures inside and outside temperatures, flow rates, differential pressures, motor temperatures, and relative humidity.

The CR5000 can monitor and control pumps, fans, and starter motors in an HVAC system.

- Mining—monitors mine ventilation, slope stability, convergence, and equipment performance.
- Process monitoring and control—provides on-line quality control while minimizing production downtime.
- Laboratory—can serve as a monitoring device to record parameters over time and can also be used to regulate and control test conditions.
- Aerospace/aviation—can endure the rigors of space travel and provide acceleration, structural, and equipment performance measurements.
- Utilities and energy—monitors conditions at power generation plants (hydroelectric, solar, and wind), terminals, substations, oil and gas pumping facilities, commercial and residential consumer sites, and along transmission lines.

Wide operating temperature ranges, solar-, AC- or battery-powered operation, wireless communications, and reliable performance make our systems ideal for unattended monitoring.

CR5000 Specifications

Electrical specifications are valid over a -25° to +50°C range unless otherwise specified; non-condensing environment required. To maintain electrical specifications, Campbell Scientific recommends recalibrating dataloggers every two years. We recommend that you confirm system configuration and critical specifications with Campbell Scientific before purchase.

PROGRAM EXECUTION RATE

The CR5000 can measure one channel and store the result in 500 µs; all 40 single-ended (SE) channels can be measured in 8 ms (5 kHz aggregate rate).

ANALOG INPUTS

20 differential (DF) or 40 single-ended (SE) individually configured. Channel expansion provided by AM16/32B and AM25T multiplexers.

RANGES, RESOLUTION, AND TYPICAL INPUT NOISE: Basic Resolution (Basic Res) is the A/D resolution of a single conversion. Resolution of DF with input reversal is half the Basic Res. Noise values are for DF with input reversal; noise is greater with SE.

Input Rng (mV)	Basic Res (µV)	0 Int. (µV RMS)	250 µs Int. (µV RMS)	20/16.7 ms Int. (µV RMS)
±5000	167	70	60	30
±1000	33.3	30	12	6
±200	6.67	8	2.4	1.2
±50	1.67	3.0	0.8	0.3
±20	0.67	1.8	0.5	0.2

ACCURACY[1]:
±(0.05% of reading + offset), 0° to 40°C
±(0.075% of reading + offset), -25° to 50°C
±(0.10% of reading + offset), -40° to 85°C (-XT only)

[1]The sensor and measurement noise is not included and the offsets are the following:

Offset for DF w/input reversal = Basic Res + 1.0 µV
Offset for DF w/o input reversal = 2Basic Res + 2.0 µV
Offset for SE = 2Basic Res + 10 µV

MINIMUM TIME BETWEEN VOLTAGE MEASUREMENTS:

Zero Integration:	125 µs
250 µs Integration:	475 µs
16.7 ms Integration:	19.9 ms
20 ms Integration:	23.2 ms

INPUT LIMITS: ±5 V

DC COMMON MODE REJECTION: >100 dB with input reversal (>80 dB without input reversal)

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

SUSTAINED INPUT VOLTAGE W/O DAMAGE: ±16 Vdc

INPUT CURRENT: ±2 nA typ., ±10 nA max. @ 50°C

INPUT RESISTANCE: 20 Gohms typical

ACCURACY OF BUILT-IN REFERENCE JUNCTION THERMISTOR (for thermocouple measurements):
±0.25°C, 0° to 40°C
±0.5°C, -25° to 50°C
±0.7°C, -40° to 85°C (-XT only)

ANALOG OUTPUTS

4 switched voltage; 4 switched current; 2 continuous voltage; switched outputs active only during measurements, one at a time.

RANGE: Voltage outputs programmable between ±5 V; current outputs programmable between ±2.5 mA

RESOLUTION: 1.2 mV for voltage outputs; 0.6 µA for current outputs

ACCURACY: ±10 mV for voltage outputs; ±10 µA for current outputs

CURRENT SOURCING: 50 mA for switched voltage; 15 mA for continuous

CURRENT SINKING: 50 mA for switched voltage; 5 mA for continuous (15 mA w/selectable option)

COMPLIANCE VOLTAGE: ±5 V for switched current excitation

RESISTANCE MEASUREMENTS

Provides voltage ratio measurements of 4- and 6-wire full bridges, and 2-, 3-, 4-wire half bridges. Direct resistance measurements available with current excitation. Dual-polarity excitation is recommended.

VOLTAGE RATIO ACCURACY[2]: Assumes input and excitation reversal and an excitation voltage of at least 2000 mV.

±(0.04% Reading + Basic Res/4) 0° to 40°C
±(0.05% Reading + Basic Res/4) -25° to 50°C
±(0.06% Reading + Basic Res/4) -40° to 85°C (-XT)

ACCURACY[2] WITH CURRENT EXCITATION: Assumes input and excitation reversal, and an excitation current, I_x, of at least 1 mA.

±(0.075% Reading + Basic Res/2I_x) 0° to 40°C
±(0.10% Reading + Basic Res/2I_x) -25° to 50°C
±(0.12% Reading + Basic Res/2I_x) -40° to 85°C (-XT)

[2]The sensor and measurement noise is not included.

PERIOD AVERAGING MEASUREMENTS

The average period for a single cycle is determined by measuring the duration of a specified number of cycles. Any of the 40 SE analog inputs can be used; signal attenuation and ac coupling may be required.

INPUT FREQUENCY RANGE:

Input Range	Signal (peak to peak) Min.	Max[3]	Min. Pulse W.	Max Freq.
±5000	600 mV	10 V	2.5 µs	200 kHz
±1000	100 mV	2.0 V	5.0 µs	100 kHz
±200	4 mV	2.0 V	25 µs	20 kHz

[3]Maximum signals must be centered around datalogger ground.

RESOLUTION: 70 ns/number of cycles measured

ACCURACY: ±(0.03% of Reading + Resolution)

PULSE COUNTERS

Two 16-bit inputs selectable for switch closure, high frequency pulse, or low-level ac.

MAXIMUM COUNT: 4×10^9

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: 400 kHz
Maximum Input Voltage: ±20 V
Voltage Thresholds: Count upon transition from below 1.5 V to above 3.5 V at low frequencies. Larger input transitions are required at high frequencies because of 1.2 µs time constant filter.

LOW-LEVEL AC MODE: Internal ac coupling removes dc offsets up to ±0.5 V.

Input Hysteresis: 15 mV
Maximum ac Input Voltage: ±20 V
Minimum ac Input Voltage:

Sine wave (mV RMS)	Range (Hz)
20	1.0 to 1000
200	0.5 to 10,000
1000	0.3 to 16,000

DIGITAL I/O PORTS

8 ports selectable as binary inputs or control outputs.

OUTPUT VOLTAGES (no load): high 5.0 V ±0.1 V; low < 0.1 V

OUTPUT RESISTANCE: 330 ohms

INPUT STATE: high 3.0 to 5.3 V; low -0.3 to 0.8 V

INPUT RESISTANCE: 100 kohms

SWITCHED 12 V

Two independent 12 V unregulated sources switched on and off under program control. Thermal fuse hold current = 900 mA @ 20°C, 650 mA @ 50°C, 360 mA @ 85°C.

EMI and ESD PROTECTION

The CR5000 is encased in metal and incorporates EMI filtering on all inputs and outputs. Gas discharge tubes provide robust ESD protection on all terminalblock inputs and outputs. The following European CE standards apply.

EMC tested and conforms to BS EN61326:1998.

Details of performance criteria applied are available upon request.

Warning: This is a Class A product. In a domestic environment this product may cause radio interference in which case the user may be required to correct the interference at the user's own expense.

CPU AND INTERFACE

PROCESSOR: Hitachi SH7034

MEMORY: Battery-backed SRAM provides 2 Mbytes for data and operating system use with 128 kbytes reserved for program storage. Expanded data storage with PCMCIA type I, type II, or type III card, or CF card (requires an adapter).

DISPLAY: 8-line-by-21 character alphanumeric or 128 x 64 pixel graphic LCD display w/backlight.

SERIAL INTERFACES: Optically isolated RS-232 9-pin DCE port for computer or non-CSI modem connection. CS I/O 9-pin port for Campbell Scientific peripherals.

BAUD RATES: Selectable from 1,200 to 115,200 bps. ASCII protocol is eight data bits, one start bit, one stop bit, no parity.

CLOCK ACCURACY: ±1 minute per month, -25° to +50°C; ±2 minute per month, -40° to +85°C

SYSTEM POWER REQUIREMENTS

VOLTAGE: 11 to 16 Vdc

TYPICAL CURRENT DRAIN: 400 µA software power off; 1.5 mA sleep mode; 4.5 mA at 1 Hz (200 mA at 5 kHz) sample rate.

INTERNAL BATTERIES: 7 Ah rechargeable base (optional); 1650 mAh lithium battery for clock and SRAM backup, 10 years of service typical, less at high temperatures.

EXTERNAL BATTERIES: 11 to 16 Vdc; reverse polarity protected.

PHYSICAL SPECIFICATIONS

SIZE: 9.8" x 8.3" x 4.5" (24.7 cm x 21.0 cm x 11.4 cm) Terminal strips extend 0.4" (1.0 cm).

WEIGHT: 4.5 lbs (2.0 kg) with low-profile base; 12.2 lbs (5.5 kg) with rechargeable base

WARRANTY

3 years against defects in materials and workmanship.

Kontroll- og referanseside/ Review and reference page

Dokumentinformasjon/*Document information*		
Dokumenttittel/*Document title* Steel sheet piles as measures against rapid mass flows		**Dokumentnr./*Document no.*** 20150226-01-R
Dokumenttype/*Type of document* Rapport / Report	**Distribusjon/*Distribution*** Fri/Unlimited	**Dato/*Date*** 2015-06-22 **Rev.nr.&dato/Rev.no.&date** 0 /
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