In-Situ Stress/Property Measurements

for Quantitative Design and Construction

SERATA STRESS/PROPERTY MEASUREMENT PROBE

EASE OF USE

Totally automated probe enables accurate, fast and efficient measurement of underground stress state and material properties.

FAST AND EFFICIENT

Complete measurement and analysis for each location can be accomplished in less than one hour.

REPEATABILITY

Measurements can be repeated at the same borehole position for recording stress variation as a function of time.

INHOMOGENEOUS GROUND

The probe is capable of performing effective measurements in most ground conditions.

Serata Geomechanics Corporation

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Overview

Serata Geomechanics Corporation (SGC) offers **Serata Stress/Propertymeter (Stressmeter)** to measure stress state and material properties, two basic inputs required for digital optimization of earthwork.

The Stressmeter was conceived and developed by the late Dr. Shosei Serata who spent over 30 years in the application of scientific and engineering principles to the acquisition, interpretation, and use of knowledge of materials of the Earth's crust for the solution of engineering problems. The Stressmeter has been applied to design and construction for mining, tunnel, dam, underground space and oil & gas storage projects. Field examples are shown in the next page.

The system consists of a Stressmeter Probe and proprietary Software for data acquisition and analysis to provide fully-automated measurements for stress state and material properties by observing force balance between the internal probe loading force and existing rock stress. The Stressmeter provides measurements for fast and reliable in-situ stress and material properties to improve design, enhance safety, which resulting cost savings to engineering projects.

A stress measurement principle was experimentally devised by utilizing the single-fracture plane method. (see reference on page 8) Accurate stress determination is made possible by the direct force balance achieved between loading pressure of the probe (p_N) and ground stress (σ_N) acting normal to the single-fracture plane at a moment of reopening the plane.

In a process of the stress measurement, material properties are automatically disclosed with regard to orientation of the fracture plane. The material property coefficients are obtained by utilizing computer graphics on site in real-time.

The Stressmeter operates on the Single-Fracture method and can be used in inhomogeneous and intact ground. The Stressmeter is capable of on-site data analysis and graphical presentation at every step of the measurement process. One cycle of measurements takes about 30 minutes to automatically calculate **elastic rigidity, deformation rigidity, elastic modulus, deformation modulus, ground consolidation, fracture pressure, reopening pressure, tensile strength and normal stress in four directions.** An example of the calculations is shown on the following pages.

The system is compact and easy to transport by ground or air to any desired location. Details of the Stressmeter are explained in the following pages.

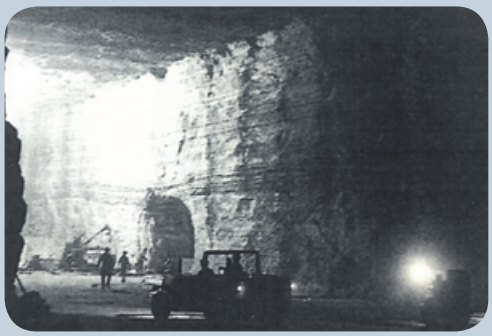
Field Applications

Since 1978, in the course of development of the Serata Stress/Propertymeter, several types of Stressmeters have been used to conduct stress measurements in various ground conditions. The photographs show typical applications of the Stressmeters during this period.

Mining Industry

Design of new mines and evaluation of existing mines, simple, fast and precise measurements, providing data for evaluation of mine safety and production economics regardless of the type of ground or mining methods.

Hard rock mining, Missouri, USA



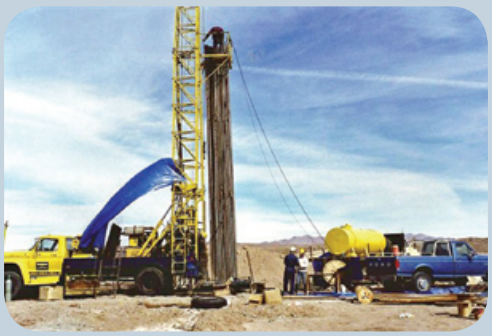
Salt mining, Ontario, Canada

Coal mining, Kentucky, USA

Coal mining, Colorado, USA

Construction Industry

The Stressmeter can be used for 1) digital monitoring of existing dams to evaluate long-term safety, 2) determination of stress state and material properties for tunnel design, and 3) direct monitoring of active condition for analysis of structures and safety of slopes and construction sites.



Deep well construction, USA

Tunnel construction, Japan

Deep well construction, USA

Existing dam, USA

Serata Stressmeter

The Serata Stressmeter System incorporates full computerization of hardware and software, enabling on-site data analysis and graphical presentations at every step of the measurements.

System Components

- Stressmeter Probe: operational unit of the System with loading/electronic sections
- Caliper Probe: borehole diameter verification probe
- Operating Rods: up to 30m (100 ft.) set of probe manipulating rods
- Hydraulic Pump: portable electric pump capable of 70 MPa (10,000 psi)
- Hydraulic Hose: up to 300m (1,000 ft.)
- Power Cable: up to 300m (1,000 ft.)
- Junction Box: converts data protocols and accepts commands from the Notebook computer
- Remote Controller: handheld controller
- Notebook Computer: equipped with probe data acquisition and analysis software

Stressmeter Specifications

- Diameter: 63.5 mm (2.5 in)
- Length: 1,660 mm (65.4 in)
- Weight: 9.1 kg (20 lbs)
- Operating Temperature: -25° to 60° C (water sealed)
- Maximum Pressure: up to 70 MPa (10,000 psi)
- Maximum Depth: up to 300 m (1,000 ft)
- Vertical Measurement Range: 0 - 360° (± 2°)
- Horizontal Measurement Range: 0 - 360° (± 1°)
- Power Supply: 110 – 240VAC 50/60 Hz, 1.3 KW, 24VDC
- Measurement Accuracy: ± 5%

Stressmeter

Caliper

Stressmeter Implementation

Borehole Requirements

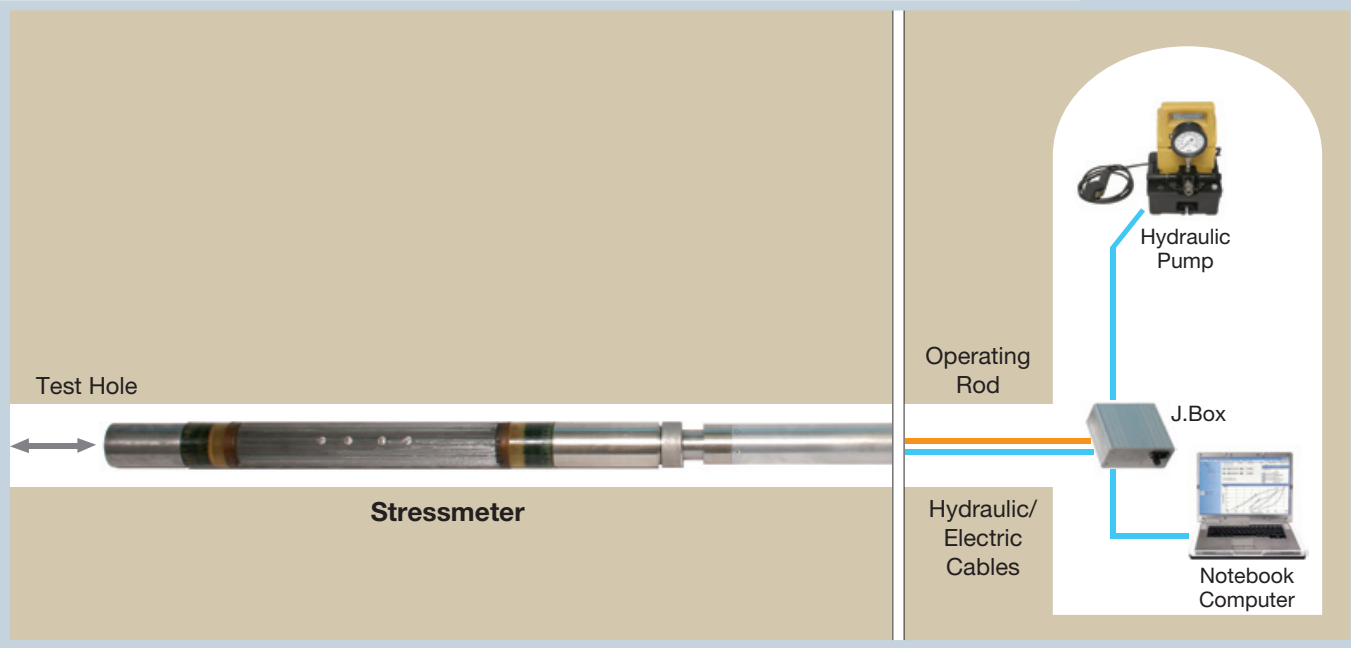
Test segment of the borehole must be drilled to a final diameter of 65-66mm by a two-stage procedure. Best results are obtained by first drilling a 63.5 mm hole and then reaming/polishing the hole to 66 mm. The caliper determines diameter by taking four measurements around the hole at 45-degree intervals. In soft or fractured ground the borehole must be stabilized prior to testing.

Stressmeter Installation

To install the Stressmeter in a borehole 1) place the Stressmeter at any measurement depth (usually less than 100 m) by using manual operating rods and 2) activate automatic stress measurement cycle by Notebook computer or Remote Controller. Vertical measurements can be made to depths up to 300 m by utilizing a hanging system. Time required to setup the system is 1-2 hours for shallow boreholes.

Stressmeter Operation

The Stressmeter is designed for operation by one or two engineers. Time required for a complete one-cycle measurement is about 10 minutes after the Stressmeter is placed in the borehole. All the data can be monitored and stored in real-time on the Notebook computer. Automatic repeated measurements can be done by programming the number of cycles. Final results are calculated and obtained by the Software within 30 minutes.



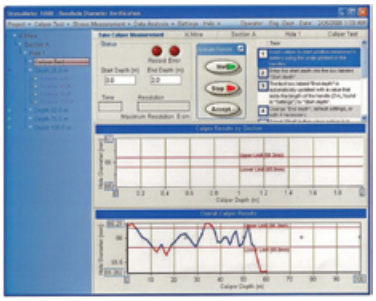
Safety Features

The System has a built-in comprehensive safety mechanism, i.e., 1) automatic shut-off high-pressure pump, 2) oil leak detection by the screen level indicator, 3) LVDT shut-off function to protect Probe diameter expansion, 4) preset maximum pumping time, 5) preset oil pressure shut-off switch to set the upper limit and 6) interlocking system between the Stressmeter and Notebook computer to confirm system connection.

Operation Software

The Software is designed to maximize the flexibility of data management by 1) site, 2) borehole and 3) data. This flexibility allows engineers to manage multiple testing projects at a single site. The software provides step-by-step instructions on the screen for Stressmeter operation.

Graphical presentations and data obtained by the Software are shown below.



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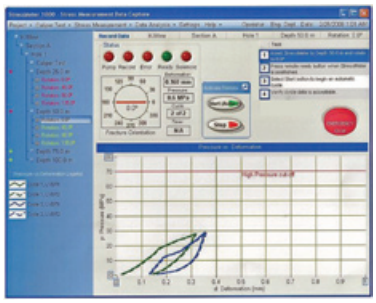
Caliper Summary

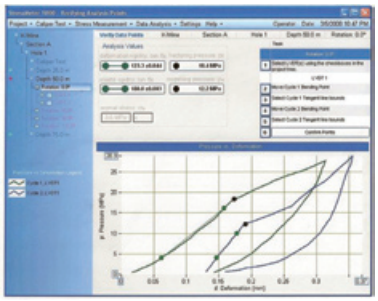
Project: K-Mine; Section: Section A; Hole; Hole 1; Caliper Test

Segment	Minimum	Maximum	Average	Std. Dev.	Points	Condition
0.00 to 3.49 m	66.20	68.28	66.3	0.02	36	out of spec (> 66.2 mm)
3.49 to 10.86 m	65.80	66.20	66.0	0.11	75	within spec
10.86 to 13.85 m	65.70	65.80	65.8	0.03	31	out of spec (< 65.8 mm)
13.85 to 15.15 m	65.80	65.86	65.8	0.02	14	within spec
15.15 to 18.44 m	65.63	65.80	65.7	0.05	34	out of spec (< 65.8 mm)
18.44 to 32.97 m	65.80	66.19	66.0	0.09	164	within spec
32.97 to 36.71 m	66.19	66.29	66.3	0.03	60	out of spec (> 66.2 mm)
36.71 to 51.90 m	65.81	66.20	66.0	0.10	241	within spec
51.90 to 52.28 m	66.20	66.24	66.2	0.01	7	out of spec (> 66.2 mm)
52.28 to 54.62 m	65.80	66.20	65.9	0.13	38	within spec
54.62 to 59.95 m	65.28	65.80	65.4	0.17	85	out of spec (< 65.8 mm)

Caliper data and results



Stress measurement data capture



Stressmeter data analysis and results

Remote Controller

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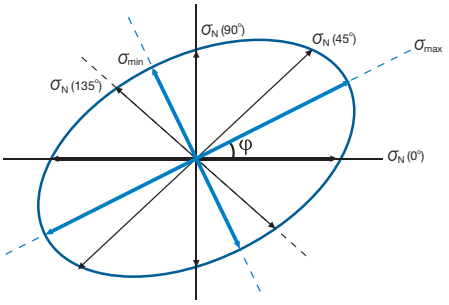
Summary of calculations on stress mesurement data

Section: A
Hole: 1
Depth: 10.0m

	Rotation	0.0°	45.0°	90.0°	135.0°	unit
$\tan\theta_E$	Elastic rigidity	120.71	120.71	120.71	120.71	MPa/mm
$\tan\theta_D$	Deformation rigidity	188.70	257.64	234.33	195.88	MPa/mm
E_E	Elastic modulus	5.11	4.38	4.38	4.38	MPa
E_D	Deformation modulus	7.99	9.36	8.51	7.12	MPa
$\Delta D/D/p_{max}$	Ground consolidation	0.09	0.10	0.10	0.10	1/MPa
p_F	Fracturing pressure	18.36	18.30	18.30	18.13	MPa
p_N	Reopening pressure	12.21	15.81	11.77	12.00	MPa
T	Tensile strength	0.00	0.00	0.00	0.00	MPa
σ_N	Normal stress	3.65	4.12	2.84	2.69	MPa

Stress State:
σ_{max} = 4.30 MPa
σ_{min} = 2.51 MPa
φ = 31.0°



Stress envelop determination using stress measurements

List of Major Projects

Projects Utilizing Serata Stress/Property Meters

The following list shows major projects since 1975 that used Serata Stress/Propertymeter with different probe diameters in different ground conditions. .

No.	Year	Client	Industry	Probe	Project	Remarks
1	1975	Japanese Government	tunnel	P	undersea ground measurement/analysis	Seikan Kensetsu
2	1978	Japanese Government	tunnel	S	undersea ground measurement/analysis	Seikan Kensetsu
3	1980	JDC Corporation	storage	S	safety analysis for nuclear power plant	Chubu Elec. Co.
4	1982	JDC Corporation	storage	P	safety analysis for nuclear power plant	Chubu Elec. Co.
5	1983	JDC Corporation	storage	S	safety analysis for nuclear power plant	Shikoku Elec. Co.
6	1984	JDC Corporation	storage	P	safety analysis for nuclear power plant	Shikoku Elec. Co.
7	1985	Peabody Coal Co.	coal	S/P	digital optimization design/field adaptation	St. Louis, MO
8	1986	Jim Walter Resources	coal	S/P	digital optimization of deep coal mining	Somerset, CO
9	1988	Blue Diamond Coal Co.	coal	S/P	digital optimization design/field adaptation	Knoxville, TN
10	1989	US Government	nuclear waste	S/P	initial evaluation of underground condition	Yucca Mountain, NV
11	1992	Sifto Canada, Inc.	salt	S/P	design & instrumentation of falling mine	Goderich, Ontario
12	1993	Japanese Government	construction	S	S/P measurements for E.Q. prediction	Kensetsusho
13	1995	Japanese Government	tunnel	S	digital optimization of earthwork	Donen
14	1997	Indian Government	coal	S	stress measurement research	CMRI
15	1998	Japanese Government	deepwell	P	develop. of deepwell remote measurement	Dengen Kaihatsu
16	1999	SGC Research Project	underground	S	stressmeter test project at research lab.	Pinawa, Canada
17	2000	NSA Engineering	coal	S	digital optimization of underground mine	Bowie, CO

Remarks: P: Propertymeter, S: Stressmeter, S/P: Stress/Propertymeter

Comparison with Other Methods

Comparison with Other Methods

Characterizations of the Stressmeter are categorically listed and compared with conventional methods of overcoring and hydrofracturing in the following chart.

Serata Method Compared with Conventional Methods in Stress & Properties Measurements

Category / Method	Hydrofracturing Method	Overcoring Method	Serata Method*1
Simultaneous Measurement of Stress State & Material Properties	not possible	not possible	**automatically**
Application Distance	not applicable at shallow depth	not applicable at great depth	**shallow to great up to 300 m**
Maximum Probe Pressure within Borehole	up to 100 MPa	not applicable	**up to 70 MPa (S-1000 Model)**
Automation of Measurement, Analysis & Graphic Display on Site	not possible	not possible	**totally automated on-site in real-time**
Requirement of Additional Supporting Equipments	required	required	**not required**
Core Specimen Recovery and Laboratory Testing	required	required	**not required**
Application to Heterogeneous Ground	difficult	difficult	**yes**
Applicability to Complex & Inhomogeneous Ground	difficult	difficult	**yes**
Precision of Stress Measurement	no better than ± 20 %	no better than ± 20 %	**better than ± 10 %**
Time Requirement per Single Measurement	more than 1 to 10 days	more than 0.5 to 2 days	**less than 1 hr.**
Number of Possible Repeated Measurement at Same Position	0	0	**as many as needed**
Economical Effectiveness	poor to good	poor to good	**excellent**

*1 : Serata Shosei, 2006, Invention of Automatic Stress/Property Measurement Probe for Earthwork Optimization, presented at International Symposium on In-situ Rock Stress - June 19-21, 2006, Trondheim, Norway, published in ISBN 0-415-40163-1

Patents

U.S. Patent No. 7,513,167 B1, Japanese Patent Nos. 2875204 & 2948527

Trial use of the Probe is available.

Details of the arrangement can be discussed.

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